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RF Network Selection in a Rule-Based System

NOSC Project ZE68: Cost Metric Algorithms for Internetwork Applications

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ADMINISTRATIVE INFORMATION

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INTRODUCTION

BACKGROUND

This Independent Exploratory Development (IED) project has addressed the problem of dynamically selecting good RF subnet resources to service transmission requests in a multi-internet environment. The approach has been to develop and implement "cost-metric algorithms" for selecting a subnet based on behavior statistics and on policy considerations such as message priority and subnet preference. Cost involves such factors as reliability, stability, and efficiency.

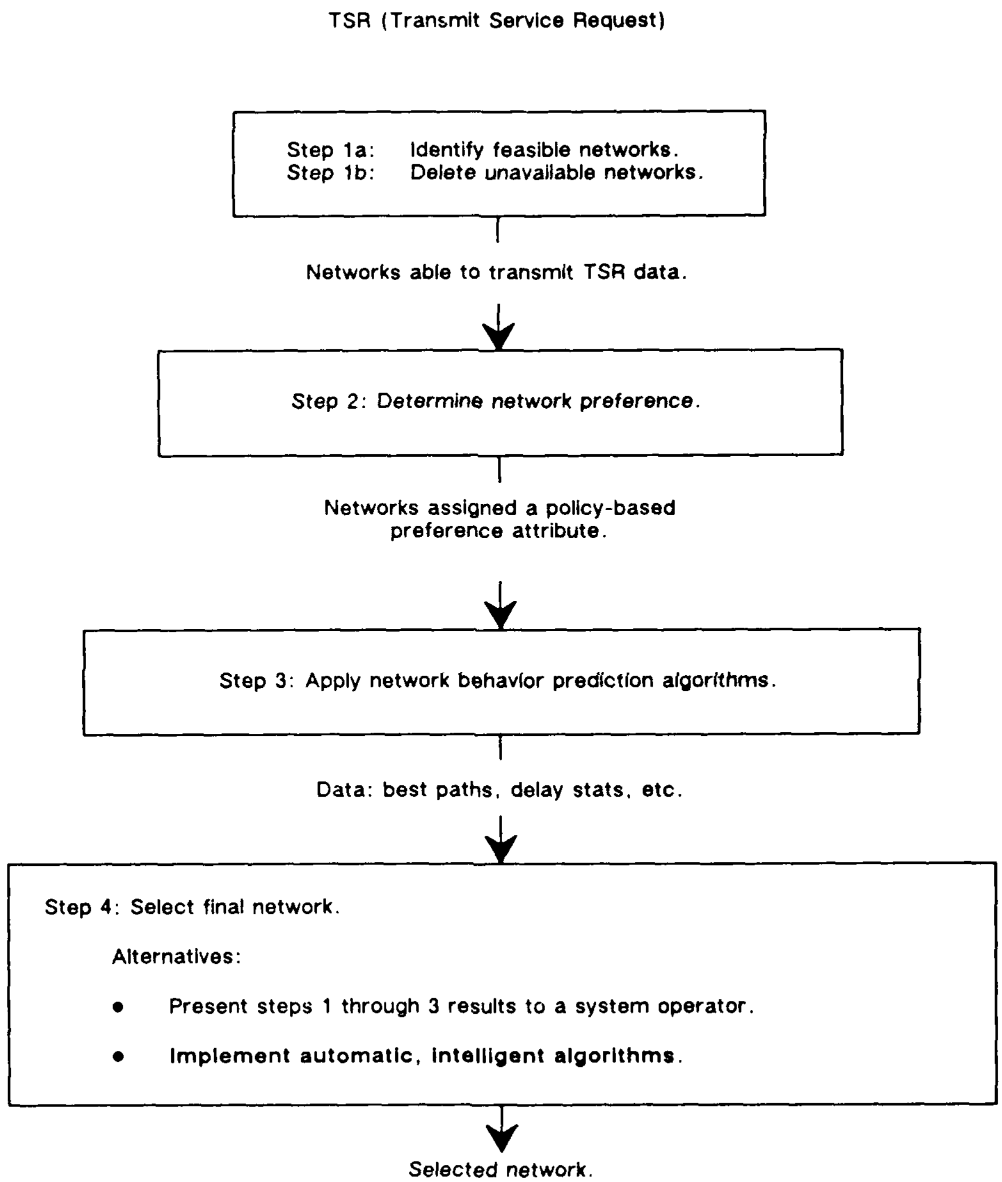
When this project began in Fiscal Year 1988, the investigation of nontraditional techniques such as artificial intelligence and fuzzy set theory was not envisioned. The project took a new direction midyear in FY 88, when conventional approaches were judged to be inadequate. The techniques investigated in the second half of FY 88 included neural nets, fuzzy logic, and expert systems. The neural net approach did not look promising and was not pursued. Fuzzy set decision methods did show promise, so those investigations were continued. The focus of the project returned to developing suitable algorithms involving "value functions" very much like the cost functions envisioned by the originators of the project. A rule-based expert system shell was chosen as the best development tool for implementing the algorithms and the fuzzy decision methods. In particular, the C-Language Integrated Production System (CLIPS), a NASA development [1], was found to have the right features for this task. The development and coding of selection algorithms began in late FY 88. The results of the FY 88 investigations are summarized in [2].

The selection algorithms used in this project were devised within the framework of the communications architecture of the Unified Networking Technology (UNT) project, a major Navy technology project at NOSC. Under that project, a simulation testbed is being developed, and the resulting algorithms are to be tested in a simulation environment. Figure 1 illustrates the relationship of the IED project with the UNT Project. Steps 1 through 3 are being implemented in the Multinetwork Controller (MC). These steps are discussed later in more detail. A system operator will look at the results of steps 1 through 3 and select a network. The objective of this project has been to investigate automated alternatives. The results are applicable to other multi-internet environments involving factors similar to those considered here; i.e., propagation delays, congestion, delivery probabilities, network preference, and message priority.

DEFINITIONS

Acronyms

ATD - Advanced Technology Demonstration
EMCON - EMission CONtrol
HF ABC - High-Frequency ABC [generic network]
HF ITF - High-Frequency IntraTask Force [network]
ISO - International Standards Organization
MC - Multinetwork Controller



UNT—Unified Networking Technology
ATD—Advanced Technology Demonstration
MC—Multinetwork Controller

Figure 1. Interrelationship with the 1990 UNT ATD MC effort.

NTDS - Naval Tactical Data System
RF - Radio Frequency
SATCOM - SATellite COMmunications
TSR - Transmit Service Request
UHF LOS - UltraHigh-Frequency Line of Sight
UNT - Unified Networking Technology

Terminology

Datagram—A data unit transmitted in the packet mode on a switched data network. The units do not necessarily arrive in the same order transmitted. No error recovery or message retransmission are provided for a basic datagram service.

Gateway—A node that participates in two or more networks and has the ability to route data from one network to the other.

Internetwork (Internet)—A collection of two or more connected networks.

Layers—An architectural concept that divides the system functions into a set of layers, where each layer has well defined interfaces to the layer above and below it.

Message—The unit of data input to the system by a user. Messages are broken down into packets by the transport layer protocols.

Multicast Service—Communications between a single source and multiple destinations. Includes *broadcast* service, transmission to all other nodes in a network.

Node—A processing point on a network. Used interchangeably with *site*. A node may be a network origination/termination point or an intermediate relay point.

Point-to-point Service—Communications between a single source and a single destination.

Preference Class—A group of networks equal in their desirability for a given type of communications traffic. Groupings are determined by a battle force communications policy.

Subnet/Subnetwork

- RF Subnet/Subnetwork—The communication channels together with the processors implementing the communication protocols (layers 1 through 3 of the ISO reference model). The terms *RF communication subnetwork*, *COMM subnet*, and *link* can be used interchangeably with RF subnet.

- User Resource Subnetwork—The users, I/O devices such as terminals and printers, and the processors implementing the protocols in layers 4 through 7 of the ISO reference model.

Subscriber/User—Any device or entity that has the authority to originate or receive data. The three kinds of users considered in experiments here were voice, NTDS, and NAVMACS (using datagrams).

UNT Priority—An assigned priority (0 is highest) mapped from the priority requested by the user.[1]

SELECTION ALGORITHMS

SUBNET SELECTION

Tables 1 and 2 illustrate the algorithms chosen for implementation. These algorithms are based on those proposed for the UNT MC.[2] They are used at step 4 in figure 1. Step 1a determines which networks exist at that transmission node and are physically capable of transmission; e.g., have the necessary equipment and bandwidth. In step 1b of figure 1, availability depends primarily on EMCON conditions and on the system not being down or currently in use. Step 2 is based on a communications policy developed by battle force command, specifying primary, secondary, tertiary, etc., preferences for different kinds of traffic. This step groups networks into *preference classes.* The networks within each preference class are considered equal in their desirability as transmission candidates. If a network is not assigned a preference class for a specific data type, it is eliminated at this step. Our experiments used two preference groups, with preference group 1 containing the preferred networks. Step 3 addresses connectivity and timeliness. Both of these issues are affected by many factors: congestion on the network, number of relays that must be made, overall network throughput, electromagnetic interference, etc. Step 3 will implement probabilistic models of increasing complexity to estimate network performance. These estimates are passed to step 4 for use in making the final network selection.

For this investigation, we assumed that three particular RF subnet performance parameters would be available to the MC at step 4. These are (1) the probability of successful delivery to a destination; (2) the minimum time it takes the network to deliver a message to a destination, based on the propagation delay per hop (relay) and number of hops; and (3) current network congestion.

Note in tables 1 and 2 that the main complexity for datagrams and for point-to-point voice occurs when more than one subnet meets the minimum requirements concerning message delay, congestion, and probability of delivery. The "value functions" used in these cases are of key interest here. They use the three performance parameters described above along with the preference group and (for datagrams) the UNT priority. The rationale for the value function for the datagram case was described in [2]. The values given for the weights used in the value functions are initial estimates, and should be optimized when network performance measurements are available.

[1]See Warner, C. L., L. Gutman, and D. Olsen, Interface Standards and Addressing, Code 8503 Internal Report, Naval Ocean Systems Center, March 1988. Available to qualified requesters.

[2]See Olsen, D. E., Multinet Controller Architecture Specification, Code 854 Internal Report, Version 2, Naval Ocean Systems Center, 1 September 1988. Available to qualified requesters.

Table 1. Point-to-point algorithms.

$P(i)$ = P(delivery to destination for i^{th} subnet)

$C(i)$ = Congestion threshold (C for voice, Cp for datagram)

R = TSR reliability threshold

T = TSR timeliness threshold

FROM STEP 3	VOICE Available Subnets	DATAGRAM Available Subnets
	For each subnet i, test $P(i) \geq R$.	*For each subnet* i, if congestion(i) > C(i) or if delay(i) > T, reject that subnet.
	If 0 subnets pass, refuse service.	If none is left, refuse service. If any remain, test $P(i) \geq R$.
	If 1 subnet passes, select it.	If 0 pass and at most 1 passed the congestion and delay tests, refuse service.
	If 2 or more, select the subnet having the maximum value *function (with weights w1=10, w2=3, w3=1, w4=9).*	If 0 pass but 2 or more passed the congestion and delay tests, test to see if the joint probability of delivery is sufficient: $1 - [1-P(i)][1-P(k)] \geq R$.
		If so, send on 2; if not, refuse service.
		If 2 or more pass, select the subnet having the the maximum value function (with weights *w1=10, w2=3, w3=1, w4=6*).

Value Function: $w1 \cdot P(i) + w2 \dfrac{C(i) - congestion(i)}{C(1)} + w3 \dfrac{T - delay(i)}{T} + w4 \cdot Prefparameter$

Prefparameter = (3 - pref class) / 3 for voice, (UNTpriority - 1) / (6 · pref class) for datagrams

Table 2. Multicast algorithms.

$P(i,j) = P(\text{delivery for } i^{th} \text{ subnet and } j^{th} \text{ destination})$

$Ni(k)$ = Number of destinations such that $P(i,j) \geq k$.

R = TSR reliability threshold

n = Number of destinations

FROM STEP 3	VOICE UHF, if available (specify p%.)	NTDS UHF and HF, if available (specify delta and alpha.)	DATAGRAM UHF and HF, if available (specify p%.)
	Select UHF if $N(R) \geq p\% \cdot n$; otherwise, refuse service.	If 1 subnet, select it; otherwise compute $\bar{P}i = (1/n)\Sigma P(i,j)$ for each subnet i. If max $\bar{P}$ - next-max $\bar{P} \geq$ delta select subnet with max $\bar{P}$; otherwise, select subnet having max Ni(alpha). Break ties by selecting subnet with max $\bar{P}$.	For each subnet i, if congestion(i) > Cp(i) or if P(i, j) < R for every destination, reject that subnet. [Cp(i) = congestion threshold = 2 · UNTpriority + degree of connectivity] If none is left, refuse service. $Ni(R) \geq p\% \cdot n$ for how many subsets? 0 subnets: refuse service. 1 subnet: select it. 2 or more: If priority is 2 or 3, send on both subnets. If priority > 3 and subnets are disjoint, send on both subnets. If priority > 3 and subnets not disjoint, send on subnet having greatest value function (w1=10, w2=2, w3=1, w4=6): $\sum_{j=1}^{n} [\; w1 \cdot P(i,j) + w2 \frac{Cp(i)\text{-congestion}(i)}{Cp(i)} + w3 \frac{T\text{-delay}(i,j)}{T} + w4 \frac{UNTpriority - 1}{6 \cdot \text{Pref class}}$

SATCOM GATEWAY SELECTION

The discussion above concerns communication within a battle group or other colocated group. Messages to distant battle forces will generally require satellite communications (SATCOM). Not all UNT nodes will have interfaces to SATCOM subnets. To get a message to a shore site to relay to a node in a distant battle force, the source node would send the message to a local node having a SATCOM interface. The general problem of routing messages in this environment is being examined in NOSC Independent Research project "Internetwork Routing for Mobile Packet Radio Networks" (see *Conclusions*), but this particular simple routing problem reduces to the current link selection problem except that the algorithm also selects the SATCOM node that will relay the message. For example, the three-step algorithm below applies to point-to-point datagram messages.

Candidate gateway nodes are specified here to be the battle group network nodes capable of relaying messages to a shore site by satellite. In the following algorithm for point-to-point transmissions, P(i, j) is the probability of successful delivery by the i_{th} subnet to the j_{th} such gateway, R is the minimum acceptable probability of delivery, and T is the maximum acceptable delay.

1. For each subnet i, if congestion(i) > Cp(i), reject that subnet. If none is left, refuse service.
2. For remaining subnet(s), reject combination (subnet i, gateway j) if delay(i, j) > T or if P(i, j) < R. If one combination remains, select it. If none is left, refuse service.
3. Select the combination (subnet i, gateway j) having the maximum value function, as given for datagrams in table 1. (Note that the second and fourth terms are a function only of the subnet.)

FUZZY LOGIC METHOD

The fuzzy-set decision method chosen for implementation was the Saaty(77)/ Yager(77) weighted method. The basic maximize-the-minimum method selects an alternative from a set of n alternatives, A = (a1, ..., ai, ..., an), based on a set of m criteria. Sets C1, ..., Cj, ..., Cm, are constructed, where Cj = (cj1, ..., cji, ..., cjn). Cj is a fuzzy subset of A, where the measure cji indicates how well alternative ai satisfies the j^{th} criterion. Yager [3] proposed weighting the measures exponentially, using Saaty's [4] method of obtaining weights on the criteria. Figure 2 illustrates this method. The notation "^" indicates the intersection (the logical AND) of two fuzzy sets. The use of exponential weighting derives from the notion of linguistic modifiers. For example, if A is the fuzzy set of large aircraft, then A^2 is the set of very large aircraft. A power larger than one reduces the grade of membership.

There are four kinds of criteria for which data likely will be available, the four corresponding to the terms of the sum in the value function. Table 3 gives a fuzzy version of the value function for point-to-point datagrams. For multicast messages, the fuzzy measures could be averaged individually over all destinations. The measures range from zero to one, and indicate how well a subnet satisfies each criterion. Note that the measure involving UNT priority and the preference class is different

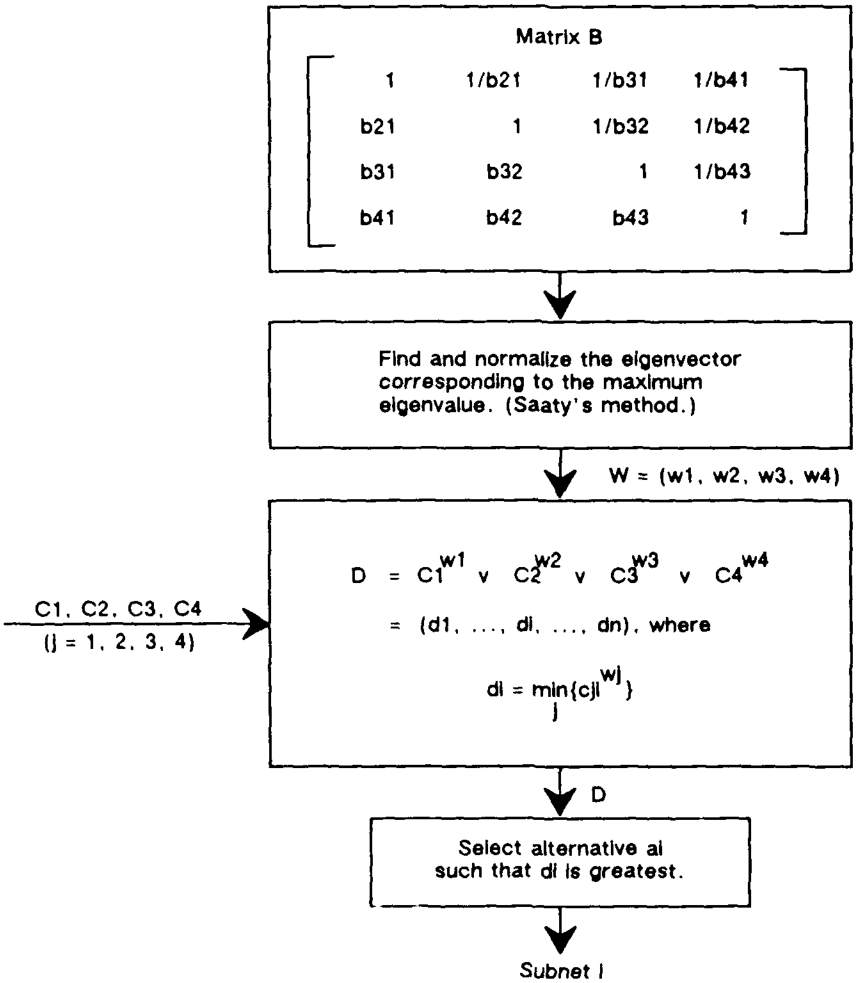


Figure 2 Saaty(77)/Yager(77) weighted fuzzy-logic method, for four criteria and n subnets. An "expert" supplies B, where bkj is the relative importance of criterion k over criterion j.

Table 3. Fuzzy measures (cji) for point-to-point datagrams.

j	Criteria	Weight Wj	Measure cji
1	Probability of delivery	10	P(delivery)
2	Congestion	2	$\frac{Cp - congestion}{Cp}$
3	Timeliness	1	$\frac{T - delay}{T}$
4	Priority and preference class	6	$\frac{9 - UNT\ priority - prefclass}{6}$

A is the set of alternative subnets; A = (a1, ..., ai, ..., an).

Cj is a fuzzy subset of A, where measure cji indicates how well subnet ai satisfies the j^{th} criterion; Cj = (cj1, ..., cji, ..., cjn).

from that used in the fourth term of the value function in table 1. This term, when used in the value function sum, plays an unusual role. It is small for high-priority messages (small UNT preference values), so that subnet performance is the deciding factor, and is large for low-priority messages, so that preference class is the overriding factor. That version of the term is unsuitable for use as a fuzzy measure in a maximize-the-minimum procedure, because it would often be the determining measure for high-priority messages. The fuzzy measure in table 3 is small for low-priority messages, and the maximum value corresponds to preference group 1 (preferred subnets).

Yager and Saaty normalize the weights to sum to unity. The normalized weights for the datagram case, for example, would be 10/19, 2/19, 1/19, and 6/19. Normalization does not affect the results (the ordering of the weighted measures remains the same), so to avoid an unnecessary operation, we chose not to normalize .

The use of the weights in the fuzzy method is notably different from their use in the value function method. The value function uses a linearly weighted sum of the measures over all criteria, and the subnet with the largest value is selected. The fuzzy method applies the weights exponentially, and we are not sure that this is appropriate, since the weights are in proportion to the importance of the criteria. In this application, the weights probably will be chosen subjectively and can vary with the operator. They can be specified directly or, for consistency, specified through the use of Saaty's matrix approach. The use of weights is discussed further in the section *Experimental Results*.

The maximize-the-minimum procedure implements the "weak link" philosopy, which in this case is to avoid the subnet having the worst single (weighted) performance factor. The tie-breaking step used in experiments was to select the system having the greatest value function.

THE CLIPS PROGRAM

The selection algorithms and fuzzy logic procedures were programmed in CLIPS, the C-language, rule-based system mentioned earlier. CLIPS was developed at the NASA/JOHNSON Space Center, and is free to U.S. Government agencies. It is highly portable and is easily integrated with external systems. We used a PC AT, but the code will run on many other computers.

SYSTEM ORGANIZATION

Table 4 shows the commonality of the different kinds of comparisons given in tables 1 and 2. Figure 3 is a diagram of the functional organization of the sets of rules in the CLIPS program. Note the rulesets (the bold boxes) that are common to more than one message type. Appendix A lists the rule names in the individual rulesets. The rulesets in the file *xcommon* correspond to the bold boxes in figure 3.

Table 4. Decision comparisons and their commonality.

	Multicast			Point-to-Point		
Comparisons	Voice	NTDS	Gram	Voice	Gram	Common
congestion(i)≤C(i)	—	—	✓	—	✓	✓
delay(i)≤T	—	—	—	—	✓	—
P(i)≥R	—	—	—	✓ & joint	✓	✓
$\max_j \{P(i,j) \geq R\}$	—	—	✓	—	—	—
i.e., Ni(R)≥1	—	—	—	—	—	—
Ni(R)≥D	✓	—	✓	—	—	✓
$\max_i$ Ni(alpha)	—	✓	—	—	—	—
$\max_i \overline{Pi}$	—	✓	—	—	—	—
Disjoint	—	—	✓	—	—	—
Value Function	—	—	✓ $\sum_j$	✓	✓	✓

P(i), P(i, j) — *Probability of delivery for* i^{th}subnet.
Ni(k) — Number of destinations such that P(i, j) > k.

The algorithms were coded in such a way that they will work with any number of candidate subnets, although the initial demonstration under the UNT project will involve only two, UHF LOS and HF ITF. The only exception to this is the computation of the value function for the multicast datagram, where the greatly increased complexity for a variable number of candidates would result in inefficient operation in the near term.

EXAMPLES OF RULES

The three rules below are in ruleset 1 of the file *xcommon*, and apply to point-to-point and multicast datagrams. The test-count iteration is used in a stopping rule; the next comparisons begin when the fact (*testcount_c 0*) appears in the database. A *TSRdd* is a package of derived data based largely on recent subnet performance, and is created when a transmit service request (TSR) is received. The second and third rules could be combined into one by using an if-then mechanism on the right-hand side of the rule. (In fact, the three rules could be combined into one.) The programming guide states, however, that it is usually better to write two rules than to use the if-then option.

```
(defrule test_congestion1
    ?x <-(test_congestion ?net)
    (current_TSRdd ?tsrdd)
    (?tsrdd congestion ?net ?congestion)
    (?tsrdd max_congestion ?net ?thr)
=>
    (assert (compare_c ?net ?congestion ?thr))
    (retract ?x))

(defrule test_congestion2
    ?x <-(compare_c ?net ?congestion ?thr)
    (test (<= ?congestion ?thr))
    ?y <-(testcount_c ?count)
=>
    (assert  (uncongested ?net)
             (testcount_c =(- ?count 1)))
    (retract ?x ?y))

(defrule test_congestion3
    ?x <-(compare_c ?net ?congestion ?thr)
    (test (> ?congestion ?thr))
    ?y <-(testcount_c ?count)
=>
    (assert  (congested ?net)
             (testcount_c =(- ?count 1)))
    (retract ?x ?y))
```

The next rule applies to point-to-point datagrams (see table 1). The letter *p* in the code represents the probability of delivery comparison. The third condition holds if all subnets failed to meet the probability of delivery requirement. If the probability that at least one of two delivers is greater than the reliability threshold (when compared in another rule), then the message is sent on two subnets. The printout statements here and in other rules are used for development and testing purposes, and would not appear in a fully automatic selection system.

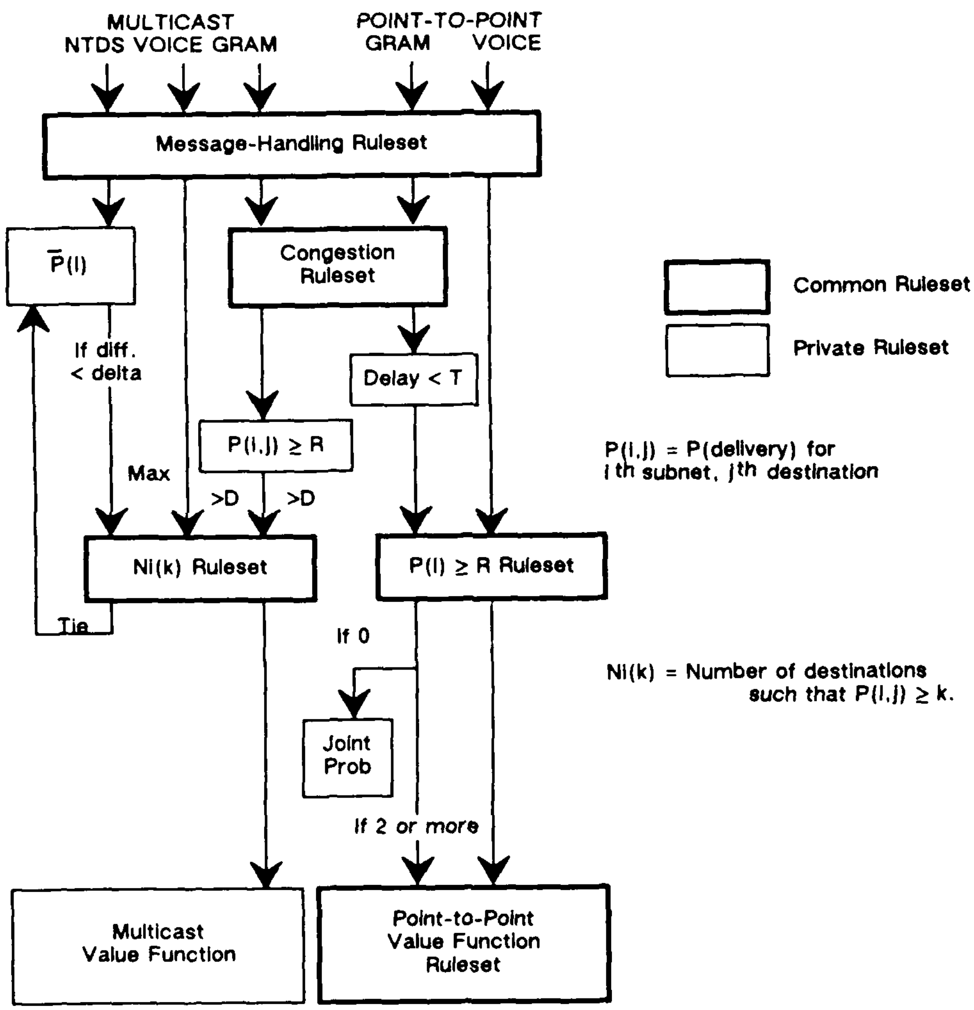


Figure 3. Organization of CLIPS rulesets.

```
(defrule still_hope "Compute joint prob for 2 with highest prob."
    ?a <-(count successes)
    (current_categ pt-pt_gram
    (passed_p_count 0)
    (failed_p_test ?net1 ?prob1)
    (failed_p_test ?net2&:(neq ?net1 ?net2) ?prob2&:(<= ?prob2 ?prob1))
    (not (failed_p_test ?net3&~?net1&?net2 ~?prob3&:(> ?prob3 ?prob2)))
=>
    (bind ?jp (- (+ ?prob1 ?prob2) (* ?prob1 ?prob2)))
    (fprintout t crlf "Joint probability of delivery for " ?net1
     " and " ?net2 " is " ?jp "." crlf)
    (assert (joint_prob ?net1 ?net2 ?jp))
    (retract ?a))
```

The example below checks for disjointness in a multicast datagram situation (see table 2). High-priority messages are sent on two subnets if the two are found to be disjoint. The last condition of this rule is there simply to take advantage of a good opportunity to retract a fact no longer needed.

```
(defrule disjoint
    ?x <-(check_disjointness ?net1 ?net2 ?tsrdd ?thr)
    (?tsrdd prob_deliv ?net1 ?dest1 ?pr1&:(>= ?pr1 ?thr))
    (not (?tsrdd prob_deliv ?net2 ?dest1 ?pr2&:(>= ?pr2 ?thr)))
    (?tsrdd prob_deliv ?net2 ?dest2 ?pr3&:(>= ?pr3 ?thr))
    (not (?tsrdd prob_deliv ?net1 ?dest2 ?pr4&:(>= ?pr4 ?thr)))
    (current_TSR ?tsr)
    ?a <-(delay_threshold ?dthresh)
=>
    (fprintout t crlf "Assign both " ?net1 " and " ?net2 " to " ?tsr "." crlf
     "Each can reach at least one destination that the other cannot." crlf)
    (retract ?x ?a))
```

EXPERIMENTAL RESULTS

Appendix B is a typescript of the selection process in CLIPS for 35 representative TSRs. The parameter values in the TSRs and TSRdds (derived data) are probably not realistic, but have the properties of relative size needed for experiments. Only about half of the TSR data is actually used by the CLIPS program; the rest is used in steps 1 through 3 of figure 1 and is included simply as information for the user in the development stage. We should later consider whether it is practical also to perform some of the steps 1 through 3 operations in CLIPS.

The main purpose of many of the CLIPS rules is to delete facts no longer needed. Note at the end of the typescript in appendix B that the facts left in the database after processing 35 messages include only some initial facts and two facts for the final message, with no facts between fact-11 and fact-3246. Minimizing the size of the fact database is important for efficient operation for all real-time systems. In this application, we have the advantage of knowing which data are obsolete, so do not have the common problem of gracefully ridding the database of aging data.

Table 5 compares the point-to-point value function results with the fuzzy-logic results. All TSRs were for datagram transmit requests, with the exception of TSR 14, which was for voice. (Recall that the voice case does not involve UNT priority.) For the datagram fuzzy cases, the lowest priority (highest UNT priority number) results in low values of the fourth measure, so that measure tends to predominate (i.e., to produce the minimum values). When it does predominate, a subnet in preference class 1 has a higher value than one in preference class 2. For these experiments, UHF LOS is in preference class 1 and the HF nets are in preference class 2, which explains why the results favor UHF LOS.

Tie breaking for the fuzzy-logic method could have continued with taking the maximum of the next-to-minimum values. However, since this is time consuming to compute, and since the principle of maximizing the minimum is essentially fulfilled by the first step, the tie-breaking rule assumed here is that the one with the maximum value function is selected.

The results obtained with the fuzzy method were usually the same as with the value function. When they differed (e.g., TSR 16 in table 5), the value function for the two selections were generally close. Slightly different results will occur with different weights. Fine tuning of the weights should be done when subnet performance statistics are available. Because of the exponential way they are used, the fuzzy weights should probably be different from the value function weights. Alternatively, instead of using the weights exponentially, we could impose them in a more linear fashion. We discuss this possibility next.

When used exponentially, large weights often result in extremely small values of the weighted measures. The criterion having the largest weight therefore tends to produce the minimums in a weighted fuzzy procedure. A subnet cannot be selected unless its performance measure for the high-priority criterion is sufficiently large. To use the weights in a nonexponential way, we divide the measure by the weight, producing the same general effect but not to the extreme that the exponential method alone does. The same messages as shown in table 5 also were run while using the criteria weights this way; i.e., by dividing each cji by wj. The only change in decision was for TSR 16. Note in table 5 that exponential weighting resulted in the selection of UHF LOS for the value function method and HF ITF for the fuzzy method. The inverse-linear weighting resulted in a tie for the fuzzy method. The minimum was the same for HF ITF and HF ABC and was smaller for UHF LOS. The tie-breaking step of choosing the subnet (in the tie) that has the greatest value function would again result in selecting HF ITF. While the decision did not change for any other TSR, in three cases the minimum value was for a different criterion than before. In general, the results for this set of messages was not significantly different for inverse-linear weighting than for exponential weighting.

A problem with the inverse-linear method occurs when the performance/priority measures tend to be large; i.e., close to unity (which was not the case here). If a measure cji for the j^{th} criterion and i^{th} subnet is unity, the weighted measure in the exponential case is unity but in the inverse-linear case is 1/wj, which is small if the criterion is very important. In the latter case, the weighted measure can often become the minimum, while other, smaller (before weighting) measures for that subnet should be the ones considered. A way to have the exponential property that the weighted measure is unity when cji is unity and yet reduce the extreme effect of a large weight is to use (1 + log wj) as the exponent. This weighting method also was tried with the TSRs in table 5, using the logarithm to the base e and to the base two. For both cases, the results differed from the value-function results significantly more than for the inverse-linear method. Curiously, where the results differed for TSR 16 in table 5, the logarithmic decision in both cases was a tie and the tie breaker resulted in the same decision as the value-function method. The results for base two were closer to the value-function results than those for base e.

While we have been using the notion here that a weight is in proportion to the importance of a criterion, Yager [3] and Saaty [4] use a descriptive scale not in accordance with this. For example, they describe a ratio of 3-to-1 of one criterion over another as "weak importance of one over the other." A ratio of 7-to-1 is is "demonstrated importance of one over the other." Their interpretation produces weights significantly different than our interpretation. When their interpretation is used with exponential weighting, a criterion slighty more important than the others has a very strong effect on the outcome. Using their interpretation with their exponential weighting would therefore make our problem worse rather than help solve it.

Weighting schemes aside, we really cannot say which method—value function or fuzzy logic—gives the best results. There is a basic philosophic difference between the two methods. The value-function method is an average-case analysis, while the fuzzy method is a worst-case analysis. The value function method is easier to implement and therefore preferable if real-time performance is a concern.

CONCLUSIONS

We hope to achieve in FY 90 a realistic interface between the CLIPS program and other internetworking code in a simulation testbed. A protocol suite and internetwork routing algorithms were developed in the Independent Research project "Internetwork Routing for Mobile Packet Radio Networks." A simulation testbed architecture also was generated, and coding of some key protocols was completed. The comprehensive test and evaluation of this internetworking concept will begin when the simulation testbed is completed; i.e., when the protocol coding is finished. CLIPS code is now being written to reformat TSR data and network performance data into CLIPS facts and to feed back selection decisions.

Testbed simulations with UNT networking code are also planned. If only a part of the network performance data needed to drive the subnet selection algorithms is available, we can temporarily use a simple, and perhaps unrealistic, simulation based on estimates. If the kinds of data provided differ from those envisioned earlier, we will need to modify the algorithms and the CLIPS code. With the modular organization of the program and the ease of programming in CLIPS, modification should not be difficult.

This project has been concerned with selecting networks in a multinetwork environment. There are also potential applications of expert systems at the individual network level. Some of these applications are discussed by Goyal and Worrest of GTE Laboratories in [5]. Most prototypes in telecommunication applications have been diagnostic expert systems. Other prototypes described in [5] include the Network Management Expert System (NEMESYS), the Expert Telecommunications Resource

Table 5. Comparison of value-function results with fuzzy-logic results.

TSR #	Eligible Subnets	Value Function	Weighted Fuzzy Measures				Prior-ity	Results
			Prob Deliv	Congestion	Timeliness	Priority/Pref		
7	HF_ITF UHF_LOS	7.18 7.68	0.00605* 0.00605*	0.0816 0.0816	0.111 0.111	0.335 1.0	2	UHF_LOS tie
9	HF_ABC HF_ITF UHF_LOS	9.63 9.68 12.68	0.00605 0.00605 0.00605	0.0816 0.0816 0.0816	0.056 0.111 0.111	0.0* 0.0* 0.0000214**	7	UHF_LOS UHF_LOS
11	HF_ABC HF_ITF	7.38 7.58	0.00839* 0.0115**	0.0816 0.0816	0.111 0.111	0.335 0.335	2	HF_ITF HF_ITF
14 (voice)	UHF_LOS HF_ITF	13.19 9.69	0.00605** 0.00253	0.0233 0.0233	0.333 0.333	0.0260 0.0000508*	NA	UHF_LOS UHF_LOS
15	HF_ABC HF_ITF UHF_LOS	8.68 8.51 11.40	0.00605 0.00605 0.0282	0.0816 0.0204 0.0204	0.111 0.222 0.111	0.00137* 0.00137* 0.0156**	5	UHF_LOS UHF_LOS
16	HF_ABC HF_ITF UHF_LOS	8.51 8.68 8.79	0.0282 0.0282** 0.00605*	0.0204* 0.0816 0.0816	0.222 0.111 0.222	0.0878 0.0878 0.335	3	UHF_LOS HF_ITF
17	HF_ABC HF_ITF UHF_LOS	7.18 8.01 7.68	0.00605* 0.0282 0.00605*	0.0816 0.0204** 0.0816	0.111 0.222 0.111	0.335 0.335 1.0	2	HF_ITF HF_ITF
18	HF_ITF UHF_LOS	7.18 8.51	0.00605* 0.0282	0.0816 0.0204**	0.111 0.222	0.335 1.0	2	UHF_LOS UHF_LOS

*minimum for subnet
**max-min

Allocation Consultant (XTRAC), and Network Control Using AI (NCAI). NEMESYS is an AT&T system that reviews information on call completions and blocking (plus explanations of the latter), and suggests actions ranging from "nothing" to rerouting calls. XTRAC allocates available resources in a network according to priority and global maximum of completed circuits. NCAI performs a distributed routing function for military packet radio networks. These and other research prototype efforts have indicated that network management is an area of great potential for future expert system development.

REFERENCES

1. *CLIPS Reference Manual, Version 4.2 of CLIPS*, Artificial Intelligence Section, Lyndon B. Johnson Space Center, April 1988.

2. Olsen, D. E., and R. A. Dillard, *Cost Metric Algorithms for Internetwork Applications*, Technical Report 1284, Naval Ocean Systems Center, April 1989.

3. Yager, R. R., "Multiple Objective Decision-Making Using Fuzzy Sets," *International Journal of Man-Machine Studies*, vol. 9, pp. 375-382, 1977.

4. Saaty, T. L., "A Scaling Method for Priorities in Hierarchical Structures," *Journal of Mathematical Psychology*, vol. 15, pp. 234-281, 1977.

5. Goyal, S. K., and R. W. Worrest, "Expert System Applications to Network Management," in *Expert System Applications to Telecommunications*, ed. J. Liebowitz, John Wiley & Sons, New York, pp. 3–44, 1988.

APPENDIX A: RULE LISTS

FILE: xmanage
PURPOSE: The user interface. Also handles the reading of a message, cleans up after it, and starts the next message.
RULES:

- user_input
- readmessage
- count_nets
- cleanup_message_1
- cleanup_TSR
- cleanup_TSRdd
- cleanup_message_2
- cleanup
- no_more
- next_message

FILE: xcommon
PURPOSE: Contains rules common to more than one message category
RULES:

Ruleset 1. Congestion rules for datagrams

- test_congestion_1
- test_congestion_2
- test_congestion_3
- stop_c_tests

Ruleset 2. Prob. of delivery rules ($P(i) \geq R$) for point-to-point msgs

- prob_check_1
- prob_check_2
- prob_check_3
- stop_prob_check
- erase_failed_p
- stop_erasing_failed
- local_cleanup_p

Ruleset 3. Point-to-Point Value Function - datagram and voice

- still_competing
- value_pref1_net
- value_pref2_net
- prelim-to-value
- pref_parameter_1
- pref_parameter_2
- compute_value
- stop_value_comps
- find_max_value
- check_for_no_ties
- check_for_ties
- cleanup_value
- end_cleanup_value

Ruleset 4. Point-to-Point Fuzzy algorithm - datagram and voice
[Also requires first few value-function rules]

fuzzy_powers
fuzzy_mins
stop_fuzzy_mins
find_fuzzy_max_1
find_fuzzy_max_2

Ruleset 5. Ni(k) computations
[number of destinations reached with prob k by ith subnet]

count_destinations
prepare_thresh_count_1
prepare_thresh_count_2
threshold_count_1
threshold_count_2
threshold_count_3
stop_threshold_count
local_cleanup_1
local_cleanup_2
local_cleanup_3
local_cleanup_4

FILE: xptgram
PURPOSE: Rules for point-to-point datagrams
RULES:

pt-pt_gram	
test_t_c	[t - *timeliness*, c - *congestion*]
test_timeliness1	
test_timeliness2	
test_timeliness3	
stop_t_c_tests	[congestion rules in xcommon]
passed_t_c_tests	
failed_c_test	
failed_t_test	
failed_t_c_tests	
end_t_c_count	
all-failed_t_c	
some_failed_t_c	
none_failed_t_c	
list_t_c_failures	
list_c_failures	
list_t_failures	
listed_t_c_failures	
wind_down	
local_cleanup_t_c	
limp_on	
one_passed_t_c	
some_passed_t_c	
one_passed_p	[p - prob of delivery; rules in xcommon]
no_hope	
still_hope	
compare_joint_prob1	
compare_joint_prob2	

FILE: xpt_v0
PURPOSE: Rules for point-to-point voice
RULES:

pt-pt_voice	
find_eligible	
none_passes_p	[p - prob of delivery; rules in xcommon]
one_passes_p	
max_pi_1	
max_pi_2	
erase_passed_p	
stop_erasing_passed	
local_cleanup_eligible	

FILE: xm_gram
PURPOSE: Rules for multicast datagrams
RULES:

multigram	
test_c_t	[c - congestion, t - timeliness;
fail_delay_test	congestion rules in xcommon]
pass_delay_test	
rejected_c	
rejected_t	
rejected_c_t	
passed_both	
end_c_t_tests	
no_candidates	
still_going	[calls Ni(k) rules in xcommon]
one_candidate	[next check % destinations reached]
only_candidate_passes	
only_candidate_fails	
multiple_candidates	[next check % destinations reached]
both_fail	
one_passes	
both_pass	
high_priority	[send on both if high]
low_priority	
disjoint	[send on both if disjoint]
not_disjoint	[compute value functions if not]
pref1_net	
pref2_net	
value_prelim	
destination_summing	
destination_sums	
cleanup_dones	
compute_value_m	
find_max_value1	
find_max_value2	
two-tied	

FILE: xm_vo&n
PURPOSE: Rules for multicast voice and NTDS
RULES:

multi_voice
multi_NTDS
find_candidates
prepare_voice
voice_passes
voice_fails
one_NTDS_candidate
compete_NTDS
prepare_avg_prob_1 [first competition for NTDS]
prepare_avg_prob_2
prepare_avg_prob_3
sum_probs
stop_summing_probs
avg_prob
stop_avg
diff_avg_probs
average_winner
close_average
cleanup_avg_1
cleanup_avg_2
find_thr_winner_1 [back-up stage for NTDS]
find_thr_winner_2
find_thr_winner_3
break_tie_1
break_tie_2

APPENDIX B: TYPESCRIPT

```
CLIPS> (batch "xcontrol")
CLIPS>
;File "xcontrol" loads other files into CLIPS and asserts initial facts:
(load "robind/xmanage")
**********
CLIPS> (load "robind/xcommon")
****************************************
CLIPS> (load "robind/xptgram")
****************************
CLIPS> (load "robind/xpt_vo")
*********
CLIPS> (load "robind/xm_gram")
********************************
CLIPS> (load "robind/xm_vo&n")
***************************
CLIPS> (assert (initial-fact)
        (subnet UHF_LOS)
        (subnet HF_ITF)
        (subnet HF_ABC)
        (weights pt-pt_gram 10 2 1 6)
        (weights multi_gram 10 2 1 6)
        (weights pt-pt_voice 10 3 1 9))
CLIPS> (run)Enter (integer) of next message:
1
How many messages do you want to process?
35
2 rules fired
CLIPS> ;First Transmit Service Request

(assert
   ("TSR_1" message_ID 1)
   ("TSR_1" source x)
   ("TSR_1" destination y)
   ("TSR_1" trans_mode pt-to-pt)
   ("TSR_1" security GENSER/TS)
   ("TSR_1" AJ 0)
   ("TSR_1" bandwidth 0)
   ("TSR_1" length 20)
   ("TSR_1" data_type datagram)
   ("TSR_1" priority 2)
   ("TSR_1" reliability 0.5)
   ("TSR_1" timeliness 90))
CLIPS>
;Derived data from steps 1-3 for first TSR

(assert
   ("TSRdd_1" UNT_priority 2)
   ("TSRdd_1" pref_class_1 UHF_LOS)
   ("TSRdd_1" pref_class_2 HF_ITF)
   ("TSRdd_1" prob_deliv UHF_LOS 0.5)
   ("TSRdd_1" prob_deliv HF_ITF 0.4)
   ("TSRdd_1" message_delay UHF_LOS 100)
   ("TSRdd_1" message_delay HF_ITF 100)
   ("TSRdd_1" congestion UHF_LOS  5)
   ("TSRdd_1" congestion HF_ITF 8)
   ("TSRdd_1" max_congestion UHF_LOS 7)
   ("TSRdd_1" max_congestion HF_ITF 7))
CLIPS> (run)
Service on "TSR_1" is refused:
```

```
   UHF_LOS is untimely although not congested.

   HF_ITF is congested and untimely.
50 rules fired
CLIPS> (run)1 rules fired
CLIPS>

(assert
   ("TSR_2" message_ID 2)
   ("TSR_2" source x)
   ("TSR_2" destination y)
   ("TSR_2" trans_mode pt-to-pt)
   ("TSR_2" security GENSER/TS)
   ("TSR_2" AJ 0)
   ("TSR_2" bandwidth 0)
   ("TSR_2" length 20)
   ("TSR_2" data_type datagram)
   ("TSR_2" priority 2)
   ("TSR_2" reliability 0.5)
   ("TSR_2" timeliness 90))
CLIPS>
(assert
   ("TSRdd_2" UNT_priority 2)
   ("TSRdd_2" pref_class_1 UHF_LOS)
   ("TSRdd_2" pref_class_2 HF_ITF)
   ("TSRdd_2" prob_deliv UHF_LOS 0.5)
   ("TSRdd_2" prob_deliv HF_ITF 0.4)
   ("TSRdd_2" message_delay UHF_LOS 80)
   ("TSRdd_2" message_delay HF_ITF 80)
   ("TSRdd_2" congestion UHF_LOS  5)
   ("TSRdd_2" congestion HF_ITF 8)
   ("TSRdd_2" max_congestion UHF_LOS 7)
   ("TSRdd_2" max_congestion HF_ITF 7),
CLIPS> (run)
Dropped as candidate subnet(s):

   HF_ITF is congested although timely.

Subnet UHF_LOS is the only timely and uncongested subnet.
Next checking its reliability.  ...

Assign subnet UHF_LOS to "TSR_2".
   It is the only subnet to pass the timeliness, congestion, and
   probability of delivery tests.
56 rules fired
CLIPS> (run)1 rules fired
CLIPS>

(assert
   ("TSR_3" message_ID 3)
   ("TSR_3" source x)
   ("TSR_3" destination y)
   ("TSR_3" trans_mode pt-to-pt)
   ("TSR_3" security GENSER/TS)
   ("TSR_3" AJ 0)
   ("TSR_3" bandwidth 0)
   ("TSR_3" length 20)
   ("TSR_3" data_type datagram)
   ("TSR_3" priority 2)
   ("TSR_3" reliability 0.5)
   ("TSR_3" timeliness 90))
CLIPS>
(assert
   ("TSRdd_3" UNT_priority 2)
   ("TSRdd_3" pref_class_1 UHF_LOS)
   ("TSRdd_3" pref_class_2 HF_ITF)
```

```
    ("TSRdd_3" prob_deliv UHF_LOS 0.5)
    ("TSRdd_3" prob_deliv HF_ITF 0.4)
    ("TSRdd_3" message_delay UHF_LOS 80)
    ("TSRdd_3" message_delay HF_ITF 100)
    ("TSRdd_3" congestion UHF_LOS  5)
    ("TSRdd_3" congestion HF_ITF 5)
    ("TSRdd_3" max_congestion UHF_LOS 7)
    ("TSRdd_3" max_congestion HF_ITF 7))
CLIPS> (run)
Dropped as candidate subnet(s):

    HF_ITF is untimely although not congested.

Subnet UHF_LOS is the only timely and uncongested subnet.
Next checking its reliability.  ...

Assign subnet UHF_LOS to "TSR_3".
    It is the only subnet to pass the timeliness, congestion, and
    probability of delivery tests.
56 rules fired
CLIPS> (run)1 rules fired
CLIPS>

(assert
    ("TSR_4" message_ID 4)
    ("TSR_4" source x)
    ("TSR_4" destination y)
    ("TSR_4" trans_mode pt-to-pt)
    ("TSR_4" security GENSER/TS)
    ("TSR_4" AJ 0)
    ("TSR_4" bandwidth 0)
    ("TSR_4" length 20)
    ("TSR_4" data_type datagram)
    ("TSR_4" priority 2)
    ("TSR_4" reliability 0.5)
    ("TSR_4" timeliness 90))
CLIPS>
(assert
    ("TSRdd_4" UNT_priority 2)
    ("TSRdd_4" pref_class_1 UHF_LOS)
    ("TSRdd_4" pref_class_2 HF_ITF)
    ("TSRdd_4" prob_deliv UHF_LOS 0.2)
    ("TSRdd_4" prob_deliv HF_ITF 0.2)
    ("TSRdd_4" message_delay UHF_LOS 80)
    ("TSRdd_4" message_delay HF_ITF 80)
    ("TSRdd_4" congestion UHF_LOS  5)
    ("TSRdd_4" congestion HF_ITF 5)
    ("TSRdd_4" max_congestion UHF_LOS 7)
    ("TSRdd_4" max_congestion HF_ITF 7))
CLIPS>
(run)
No candidate network is untimely or congested.

More than one candidate subnet.
Next checking their reliability.  ...

Joint probability of delivery for HF_ITF and UHF_LOS is 0.36000001.

Service on "TSR_4" is refused:
    No subnet or combination of subnets has a sufficiently high
    probability of successful delivery.
58 rules fired
CLIPS> (run)1 rules fired
CLIPS>
```

```
(assert
   ("TSR_5" message_ID 5)
   ("TSR_5" source x)
   ("TSR_5" destination y)
   ("TSR_5" trans_mode pt-to-pt)
   ("TSR_5" security GENSER/TS)
   ("TSR_5" AJ 0)
   ("TSR_5" bandwidth 0)
   ("TSR_5" length 20)
   ("TSR_5" data_type datagram)
   ("TSR_5" priority 2)
   ("TSR_5" reliability 0.5)
   ("TSR_5" timeliness 90))
CLIPS>
(assert
   ("TSRdd_5" UNT_priority 2)
   ("TSRdd_5" pref_class_1 UHF_LOS)
   ("TSRdd_5" pref_class_2 HF_ITF)
   ("TSRdd_5" prob_deliv UHF_LOS 0.4)
   ("TSRdd_5" prob_deliv HF_ITF 0.4)
   ("TSRdd_5" message_delay UHF_LOS 80)
   ("TSRdd_5" message_delay HF_ITF 100)
   ("TSRdd_5" congestion UHF_LOS  5)
   ("TSRdd_5" congestion HF_ITF 5)
   ("TSRdd_5" max_congestion UHF_LOS 7)
   ("TSRdd_5" max_congestion HF_ITF 7))
CLIPS> (run)
Dropped as candidate subnet(s):

   HF_ITF is untimely although not congested.

Subnet UHF_LOS is the only timely and uncongested subnet.
Next checking its reliability.  ...

Service on "TSR_5" is refused:
   Only one subnet passed the timeliness and congestion tests, and
   it failed the probability of delivery test.
55 rules fired
CLIPS> (run)1 rules fired
CLIPS>

(assert
   ("TSR_6" message_ID 6)
   ("TSR_6" source x)
   ("TSR_6" destination y)
   ("TSR_6" trans_mode pt-to-pt)
   ("TSR_6" security GENSER/TS)
   ("TSR_6" AJ 0)
   ("TSR_6" bandwidth 0)
   ("TSR_6" length 20)
   ("TSR_6" data_type datagram)
   ("TSR_6" priority 2)
   ("TSR_6" reliability 0.5)
   ("TSR_6" timeliness 90))
CLIPS>
(assert
   ("TSRdd_6" UNT_priority 2)
   ("TSRdd_6" pref_class_1 UHF_LOS)
   ("TSRdd_6" pref_class_2 HF_ITF)
   ("TSRdd_6" prob_deliv UHF_LOS 0.6)
   ("TSRdd_6" prob_deliv HF_ITF 0.4)
   ("TSRdd_6" message_delay UHF_LOS 80)
   ("TSRdd_6" message_delay HF_ITF 80)
   ("TSRdd_6" congestion UHF_LOS 5)
   ("TSRdd_6" congestion HF_ITF 5)
   ("TSRdd_6" max_congestion UHF_LOS 7)
```

```
   ("TSRdd_6" max_congestion HF_ITF 7))
CLIPS>
(run)
No candidate network is untimely or congested.

More than one candidate subnet.
Next checking their reliability.  ...

Assign subnet UHF_LOS to "TSR_6".
   It is the only subnet to pass the timeliness, congestion, and
   probability of delivery tests.
56 rules fired
CLIPS> (run)1 rules fired
CLIPS>

(assert
   ("TSR_7" message_ID 7)
   ("TSR_7" source x)
   ("TSR_7" destination y)
   ("TSR_7" trans_mode pt-to-pt)
   ("TSR_7" security GENSER/TS)
   ("TSR_7" AJ 0)
   ("TSR_7" bandwidth 0)
   ("TSR_7" length 20)
   ("TSR_7" data_type datagram)
   ("TSR_7" priority 2)
   ("TSR_7" reliability 0.5)
   ("TSR_7" timeliness 90))
CLIPS>
(assert
   ("TSRdd_7" UNT_priority 2)
   ("TSRdd_7" pref_class_1 UHF_LOS)
   ("TSRdd_7" pref_class_2 HF_ITF)
   ("TSRdd_7" prob_deliv UHF_LOS 0.6)
   ("TSRdd_7" prob_deliv HF_ITF 0.6)
   ("TSRdd_7" message_delay UHF_LOS 80)
   ("TSRdd_7" message_delay HF_ITF 80)
   ("TSRdd_7" congestion UHF_LOS  5)
   ("TSRdd_7" congestion HF_ITF 5)
   ("TSRdd_7" max_congestion UHF_LOS 7)
   ("TSRdd_7" max_congestion HF_ITF 7))
CLIPS>
(run)
No candidate network is untimely or congested.

More than one candidate subnet.
Next checking their reliability.  ...

2 subnets passed the probability-of-delivery test.
The Point-to-Point Value Function will be computed for each. ...

HF_ITF:  7.18253994
UHF_LOS:  7.68253994

Maximum Value_Funtion:  7.68253994
Assign UHF_LOS to "TSR_7".

Next computing fuzzy decision for comparison....
Weighted criteria measures for HF_ITF:
       0.00604662, 0.08163266, 0.11111111, 0.33489794
Minimum is 0.00604662.
Weighted criteria measures for UHF_LOS:
       0.00604662, 0.08163266, 0.11111111, 1
Minimum is 0.00604662.
Fuzzy selection algorithm results in a tie.
Use the above result of the value function comparsions.
```

```
75 rules fired
CLIPS> (run)1 rules fired
CLIPS>


(assert
   ("TSR_8" message_ID 8)
   ("TSR_8" source x)
   ("TSR_8" destination y)
   ("TSR_8" trans_mode pt-to-pt)
   ("TSR_8" security GENSER/TS)
   ("TSR_8" AJ 0)
   ("TSR_8" bandwidth 0)
   ("TSR_8" length 20)
   ("TSR_8" data_type datagram)
   ("TSR_8" priority 2)
   ("TSR_8" reliability 0.5)
   ("TSR_8" timeliness 90))
CLIPS>
(assert
   ("TSRdd_8" UNT_priority 2)
   ("TSRdd_8" pref_class_1 UHF_LOS)
   ("TSRdd_8" pref_class_2 HF_ITF)
   ("TSRdd_8" prob_deliv UHF_LOS 0.4)
   ("TSRdd_8" prob_deliv HF_ITF 0.4)
   ("TSRdd_8" message_delay UHF_LOS 80)
   ("TSRdd_8" message_delay HF_ITF 80)
   ("TSRdd_8" congestion UHF_LOS  5)
   ("TSRdd_8" congestion HF_ITF 5)
   ("TSRdd_8" max_congestion UHF_LOS 7)
   ("TSRdd_8" max_congestion HF_ITF 7))
CLIPS> (run)
No candidate network is untimely or congested.

More than one candidate subnet.
Next checking their reliability.  ...

Joint probability of delivery for HF_ITF and UHF_LOS is 0.63999999.

Assign both HF_ITF and UHF_LOS to "TSR_8".
58 rules fired
CLIPS> (run)1 rules fired
CLIPS>

(assert
   ("TSR_9" message_ID 9)
   ("TSR_9" source x)
   ("TSR_9" destination y)
   ("TSR_9" trans_mode pt-to-pt)
   ("TSR_9" security GENSER/TS)
   ("TSR_9" AJ 0)
   ("TSR_9" bandwidth 0)
   ("TSR_9" length 20)
   ("TSR_9" data_type datagram)
   ("TSR_9" priority 2)
   ("TSR_9" reliability 0.5)
   ("TSR_9" timeliness 90))
CLIPS>
(assert
   ("TSRdd_9" UNT_priority 7)
   ("TSRdd_9" pref_class_1 UHF_LOS)
   ("TSRdd_9" pref_class_2 HF_ITF HF_ABC)
   ("TSRdd_9" prob_deliv UHF_LOS 0.6)
   ("TSRdd_9" prob_deliv HF_ITF 0.6)
   ("TSRdd_9" prob_deliv HF_ABC 0.6)
   ("TSRdd_9" message_delay UHF_LOS 80)
```

```
   ("TSRdd_9" message_delay HF_ITF 80)
   ("TSRdd_9" message_delay HF_ABC 85)
   ("TSRdd_9" congestion UHF_LOS  5)
   ("TSRdd_9" congestion HF_ITF 5)
   ("TSRdd_9" congestion HF_ABC 5)
   ("TSRdd_9" max_congestion UHF_LOS 7)
   ("TSRdd_9" max_congestion HF_ITF 7)
   ("TSRdd_9" max_congestion HF_ABC 7))
CLIPS>
(run)
No candidate network is untimely or congested.

More than one candidate subnet.
Next checking their reliability.  ...

3 subnets passed the probability-of-delivery test.
The Point-to-Point Value Function will be computed for each. ...

HF_ABC:  9.62698364
HF_ITF:  9.68253994
UHF_LOS:  12.68253994

Maximum Value_Funtion:  12.68253994
Assign UHF_LOS to "TSR_9".

Next computing fuzzy decision for comparison....
Weighted criteria measures for HF_ABC:
       0.00604662, 0.08163266, 0.05555556, 0
Minimum is 0.
Weighted criteria measures for HF_ITF:
       0.00604662, 0.08163266, 0.11111111, 0
Minimum is 0.
Weighted criteria measures for UHF_LOS:
       0.00604662, 0.08163266, 0.11111111, 2.1433e-005
Minimum is 2.1433e-005.
Fuzzy selection algorithm recommendation:
Assign UHF_LOS to "TSR_9".
94 rules fired
CLIPS> (run)1 rules fired
CLIPS>

(assert
   ("TSR_10" message_ID 10)
   ("TSR_10" source x)
   ("TSR_10" destination y)
   ("TSR_10" trans_mode pt-to-pt)
   ("TSR_10" security GENSER/TS)
   ("TSR_10" AJ 0)
   ("TSR_10" bandwidth 0)
   ("TSR_10" length 20)
   ("TSR_10" data_type datagram)
   ("TSR_10" priority 2)
   ("TSR_10" reliability 0.5)
   ("TSR_10" timeliness 90))
CLIPS>
(assert
   ("TSRdd_10" UNT_priority 4)
   ("TSRdd_10" pref_class_1 UHF_LOS)
   ("TSRdd_10" pref_class_2 HF_ITF HF_ABC)
   ("TSRdd_10" prob_deliv UHF_LOS 0.22)
   ("TSRdd_10" prob_deliv HF_ITF 0.2)
   ("TSRdd_10" prob_deliv HF_ABC 0.18)
   ("TSRdd_10" message_delay UHF_LOS 80)
   ("TSRdd_10" message_delay HF_ITF 80)
   ("TSRdd_10" message_delay HF_ABC 80)
   ("TSRdd_10" congestion UHF_LOS  5)
```

```
    ("TSRdd_10" congestion HF_ITF 5)
    ("TSRdd_10" congestion HF_ABC 5)
    ("TSRdd_10" max_congestion UHF_LOS 7)
    ("TSRdd_10" max_congestion HF_ITF 7)
    ("TSRdd_10" max_congestion HF_ABC 7))
CLIPS> (run)
No candidate network is untimely or congested.

More than one candidate subnet.
Next checking their reliability.  ...

Joint probability of delivery for UHF_LOS and HF_ITF is 0.37600002.

Service on "TSR_10" is refused:
   No subnet or combination of subnets has a sufficiently high
   probability of successful delivery.
71 rules fired
CLIPS> (run)1 rules fired
CLIPS>

(assert
    ("TSR_11" message_ID 11)
    ("TSR_11" source x)
    ("TSR_11" destination y)
    ("TSR_11" trans_mode pt-to-pt)
    ("TSR_11" security GENSER/TS)
    ("TSR_11" AJ 0)
    ("TSR_11" bandwidth 0)
    ("TSR_11" length 20)
    ("TSR_11" data_type datagram)
    ("TSR_11" priority 2)
    ("TSR_11" reliability 0.5)
    ("TSR_11" timeliness 90))
CLIPS>
(assert
    ("TSRdd_11" UNT_priority 2)
    ("TSRdd_11" pref_class_1 UHF_LOS)
    ("TSRdd_11" pref_class_2 HF_ITF HF_ABC)
    ("TSRdd_11" prob_deliv UHF_LOS 0.48)
    ("TSRdd_11" prob_deliv HF_ITF 0.64)
    ("TSRdd_11" prob_deliv HF_ABC 0.62)
    ("TSRdd_11" message_delay UHF_LOS 80)
    ("TSRdd_11" message_delay HF_ITF 80)
    ("TSRdd_11" message_delay HF_ABC 80)
    ("TSRdd_11" congestion UHF_LOS  5)
    ("TSRdd_11" congestion HF_ITF 5)
    ("TSRdd_11" congestion HF_ABC 5)
    ("TSRdd_11" max_congestion UHF_LOS 7)
    ("TSRdd_11" max_congestion HF_ITF 7)
    ("TSRdd_11" max_congestion HF_ABC 7))
CLIPS> (run)
No candidate network is untimely or congested.

More than one candidate subnet.
Next checking their reliability.  ...

2 subnets passed the probability-of-delivery test.
The Point-to-Point Value Function will be computed for each. ...

HF_ABC:  7.38253975
HF_ITF:  7.58253956

Maximum Value_Funtion:  7.58253956
Assign HF_ITF to "TSR_11".

Next computing fuzzy decision for comparison....
```

```
Weighted criteria measures for HF_ABC:
       0.00839299, 0.08163266, 0.11111111, 0.33489794
Minimum is 0.00839299.
Weighted criteria measures for HF_ITF:
       0.01152921, 0.08163266, 0.11111111, 0.33489794
Minimum is 0.01152921.
Fuzzy selection algorithm recommendation:
Assign HF_ITF to "TSR_11".
88 rules fired
CLIPS> (run)1 rules fired
CLIPS>

(assert
   ("TSR_12" message_ID 12)
   ("TSR_12" source x)
   ("TSR_12" destination nodex)
   ("TSR_12" trans_mode pt-to-pt)
   ("TSR_12" security GENSER/TS)
   ("TSR_12" AJ 0)
   ("TSR_12" bandwidth 0)
   ("TSR_12" length 0)
   ("TSR_12" data_type voice)
   ("TSR_12" priority 0)
   ("TSR_12" reliability 0.5)
   ("TSR_12" timeliness 90))
CLIPS>
(assert
   ("TSRdd_12" pref_class_1 UHF_LOS)
   ("TSRdd_12" pref_class_2 HF_ITF)
   ("TSRdd_12" prob_deliv UHF_LOS 0.4)
   ("TSRdd_12" prob_deliv HF_ITF 0.4)
   ("TSRdd_12" message_delay UHF_LOS 80)
   ("TSRdd_12" message_delay HF_ITF 80)
   ("TSRdd_12" congestion UHF_LOS  5)
   ("TSRdd_12" congestion HF_ITF 5)
   ("TSRdd_12" max_congestion UHF_LOS 7)
   ("TSRdd_12" max_congestion HF_ITF 7))
CLIPS> (run)
Service on "TSR_12" is refused.
No subnet passed the probability of delivery test.
41 rules fired
CLIPS> (run)1 rules fired
CLIPS>


(assert
   ("TSR_13" message_ID 13)
   ("TSR_13" source x)
   ("TSR_13" destination nodex)
   ("TSR_13" trans_mode pt-to-pt)
   ("TSR_13" security GENSER/TS)
   ("TSR_13" AJ 0)
   ("TSR_13" bandwidth 0)
   ("TSR_13" length 0)
   ("TSR_13" data_type voice)
   ("TSR_13" priority 0)
   ("TSR_13" reliability 0.5)
   ("TSR_13" timeliness 90))
CLIPS>
(assert
   ("TSRdd_13" pref_class_1 UHF_LOS)
   ("TSRdd_13" pref_class_2 HF_ITF)
   ("TSRdd_13" prob_deliv UHF_LOS 0.6)
   ("TSRdd_13" prob_deliv HF_ITF 0.4)
   ("TSRdd_13" message_delay UHF_LOS 80)
   ("TSRdd_13" message_delay HF_ITF 80)
```

```
   ("TSRdd_13" congestion UHF_LOS  5)
   ("TSRdd_13" congestion HF_ITF 5)
   ("TSRdd_13" max_congestion UHF_LOS 7)
   ("TSRdd_13" max_congestion HF_ITF 7))
CLIPS> (run)
Assign subnet UHF_LOS to "TSR_13".
It is the only subnet to pass the probability of delivery test.
40 rules fired
CLIPS> (run)1 rules fired
CLIPS>

(assert
   ("TSR_14" message_ID 14)
   ("TSR_14" source x)
   ("TSR_14" destination nodex)
   ("TSR_14" trans_mode pt-to-pt)
   ("TSR_14" security GENSER/TS)
   ("TSR_14" AJ 0)
   ("TSR_14" bandwidth 0)
   ("TSR_14" length 0)
   ("TSR_14" data_type voice)
   ("TSR_14" priority 0)
   ("TSR_14" reliability 0.5)
   ("TSR_14" timeliness 90))
CLIPS>
(assert
   ("TSRdd_14" pref_class_1 UHF_LOS)
   ("TSRdd_14" pref_class_2 HF_ITF)
   ("TSRdd_14" prob_deliv UHF_LOS 0.6)
   ("TSRdd_14" prob_deliv HF_ITF 0.55)
   ("TSRdd_14" message_delay UHF_LOS 60)
   ("TSRdd_14" message_delay HF_ITF 60)
   ("TSRdd_14" congestion UHF_LOS  5)
   ("TSRdd_14" congestion HF_ITF 5)
   ("TSRdd_14" max_congestion UHF_LOS 7)
   ("TSRdd_14" max_congestion HF_ITF 7))
CLIPS> (run)
2 subnets passed the probability-of-delivery test.
The Point-to-Point Value Function will be computed for each. ...

UHF_LOS:  13.19047642
HF_ITF:  9.69047642

Maximum Value_Funtion:  13.19047642
Assign UHF_LOS to "TSR_14".

Next computing fuzzy decision for comparison....
Weighted criteria measures for UHF_LOS:
       0.00604662, 0.02332362, 0.33333334, 0.0260123
Minimum is 0.00604662.
Weighted criteria measures for HF_ITF:
       0.00253295, 0.02332362, 0.33333334, 5.0805e-005
Minimum is 5.0805e-005.
Fuzzy selection algorithm recommendation:
Assign UHF_LOS to "TSR_14".
59 rules fired
CLIPS> (run)1 rules fired
CLIPS>

(assert
   ("TSR_15" message_ID 15)
   ("TSR_15" source x)
   ("TSR_15" destination y)
   ("TSR_15" trans_mode pt-to-pt)
   ("TSR_15" security GENSER/TS)
   ("TSR_15" AJ 0)
```

```
   ("TSR_15" bandwidth 0)
   ("TSR_15" length 20)
   ("TSR_15" data_type datagram)
   ("TSR_15" priority 2)
   ("TSR_15" reliability 0.5)
   ("TSR_15" timeliness 90))
CLIPS>
(assert
   ("TSRdd_15" UNT_priority 5)
   ("TSRdd_15" pref_class_1 UHF_LOS)
   ("TSRdd_15" pref_class_2 HF_ITF HF_ABC)
   ("TSRdd_15" prob_deliv UHF_LOS 0.7)
   ("TSRdd_15" prob_deliv HF_ITF 0.6)
   ("TSRdd_15" prob_deliv HF_ABC 0.6)
   ("TSRdd_15" message_delay UHF_LOS 80)
   ("TSRdd_15" message_delay HF_ITF 70)
   ("TSRdd_15" message_delay HF_ABC 80)
   ("TSRdd_15" congestion UHF_LOS  6)
   ("TSRdd_15" congestion HF_ITF 6)
   ("TSRdd_15" congestion HF_ABC 5)
   ("TSRdd_15" max_congestion UHF_LOS 7)
   ("TSRdd_15" max_congestion HF_ITF 7)
   ("TSRdd_15" max_congestion HF_ABC 7))
CLIPS>
(run)
No candidate network is untimely or congested.

More than one candidate subnet.
Next checking their reliability.  ...

3 subnets passed the probability-of-delivery test.
The Point-to-Point Value Function will be computed for each. ...

HF_ABC:  8.68253994
HF_ITF:  8.50793648
UHF_LOS:  11.39682579

Maximum Value_Funtion:  11.39682579
Assign UHF_LOS to "TSR_15".

Next computing fuzzy decision for comparison....
Weighted criteria measures for HF_ABC:
       0.00604662, 0.08163266, 0.11111111, 0.00137174
Minimum is 0.00137174.
Weighted criteria measures for HF_ITF:
       0.00604662, 0.02040816, 0.22222222, 0.00137174
Minimum is 0.00137174.
Weighted criteria measures for UHF_LOS:
       0.02824752, 0.02040816, 0.11111111, 0.015625
Minimum is 0.015625.
Fuzzy selection algorithm recommendation:
Assign UHF_LOS to "TSR_15".
94 rules fired
CLIPS> (run)1 rules fired
CLIPS>

 (assert
   ("TSR_16" message_ID 16)
   ("TSR_16" source x)
   ("TSR_16" destination y)
   ("TSR_16" trans_mode pt-to-pt)
   ("TSR_16" security GENSER/TS)
   ("TSR_16" AJ 0)
   ("TSR_16" bandwidth 0)
   ("TSR_16" length 20)
   ("TSR_16" data_type datagram)
```

```
   ("TSR_16" priority 2)
   ("TSR_16" reliability 0.5)
   ("TSR_16" timeliness 90))
CLIPS>
(assert
   ("TSRdd_16" UNT_priority 3)
   ("TSRdd_16" pref_class_1 UHF_LOS)
   ("TSRdd_16" pref_class_2 HF_ITF HF_ABC)
   ("TSRdd_16" prob_deliv UHF_LOS 0.6)
   ("TSRdd_16" prob_deliv HF_ITF 0.7)
   ("TSRdd_16" prob_deliv HF_ABC 0.7)
   ("TSRdd_16" message_delay UHF_LOS 70)
   ("TSRdd_16" message_delay HF_ITF 80)
   ("TSRdd_16" message_delay HF_ABC 70)
   ("TSRdd_16" congestion UHF_LOS  5)
   ("TSRdd_16" congestion HF_ITF 5)
   ("TSRdd_16" congestion HF_ABC 6)
   ("TSRdd_16" max_congestion UHF_LOS 7)
   ("TSRdd_16" max_congestion HF_ITF 7)
   ("TSRdd_16" max_congestion HF_ABC 7))
CLIPS>
(run)
No candidate network is untimely or congested.

More than one candidate subnet.
Next checking their reliability.  ...

3 subnets passed the probability-of-delivery test.
The Point-to-Point Value Function will be computed for each. ...

HF_ABC:  8.50[illegible]3648
HF_ITF:  [illegible]253994
UHF_LOS:  8.79365158

Maximum Value_Funtion:  8.79365158
Assign UHF_LOS to "TSR_16".

Next computing fuzzy decision for comparison....
Weighted criteria measures for HF_ABC:
        0.02824752, 0.02040816, 0.22222222, 0.08779151
Minimum is 0.02040816.
Weighted criteria measures for HF_ITF:
        0.02824752, 0.08163266, 0.11111111, 0.08779151
Minimum is 0.02824752.
Weighted criteria measures for UHF_LOS:
        0.00604662, 0.08163266, 0.22222222, 0.33489794
Minimum is 0.00604662.
Fuzzy selection algorithm recommendation:
Assign HF_ITF to "TSR_16".
94 rules fired
CLIPS> (run)1 rules fired
CLIPS>

(assert
   ("TSR_17" message_ID 17)
   ("TSR_17" source x)
   ("TSR_17" destination y)
   ("TSR_17" trans_mode pt-to-pt)
   ("TSR_17" security GENSER/TS)
   ("TSR_17" AJ 0)
   ("TSR_17" bandwidth 0)
   ("TSR_17" length 20)
   ("TSR_17" data_type datagram)
   ("TSR_17" priority 2)
   ("TSR_17" reliability 0.5)
   ("TSR_17" timeliness 90))
```

```
CLIPS>
(assert
   ("TSRdd_17" UNT_priority 2)
   ("TSRdd_17" pref_class_1 UHF_LOS)
   ("TSRdd_17" pref_class_2 HF_ITF HF_ABC)
   ("TSRdd_17" prob_deliv UHF_LOS 0.6)
   ("TSRdd_17" prob_deliv HF_ITF 0.7)
   ("TSRdd_17" prob_deliv HF_ABC 0.6)
   ("TSRdd_17" message_delay UHF_LOS 80)
   ("TSRdd_17" message_delay HF_ITF 70)
   ("TSRdd_17" message_delay HF_ABC 80)
   ("TSRdd_17" congestion UHF_LOS  5)
   ("TSRdd_17" congestion HF_ITF 6)
   ("TSRdd_17" congestion HF_ABC 5)
   ("TSRdd_17" max_congestion UHF_LOS 7)
   ("TSRdd_17" max_congestion HF_ITF 7)
   ("TSRdd_17" max_congestion HF_ABC 7))
CLIPS>
(run)
No candidate network is untimely or congested.

More than one candidate subnet.
Next checking their reliability.  ...

3 subnets passed the probability-of-delivery test.
The Point-to-Point Value Function will be computed for each. ...

HF_ABC:  7.18253994
HF_ITF:  8.00793648
UHF_LOS:  7.68253994

Maximum Value_Funtion:  8.00793648
Assign HF_ITF to "TSR_17".

Next computing fuzzy decision for comparison....
Weighted criteria measures for HF_ABC:
       0.00604662, 0.08163266, 0.11111111, 0.33489794
Minimum is 0.00604662.
Weighted criteria measures for HF_ITF:
       0.02824752, 0.02040816, 0.22222222, 0.33489794
Minimum is 0.02040816.
Weighted criteria measures for UHF_LOS:
       0.00604662, 0.08163266, 0.11111111, 1
Minimum is 0.00604662.
Fuzzy selection algorithm recommendation:
Assign HF_ITF to "TSR_17".
94 rules fired
CLIPS> (run)1 rules fired
CLIPS>

(assert
   ("TSR_18" message_ID 18)
   ("TSR_18" source x)
   ("TSR_18" destination y)
   ("TSR_18" trans_mode pt-to-pt)
   ("TSR_18" security GENSER/TS)
   ("TSR_18" AJ 0)
   ("TSR_18" bandwidth 0)
   ("TSR_18" length 20)
   ("TSR_18" data_type datagram)
   ("TSR_18" priority 2)
   ("TSR_18" reliability 0.5)
   ("TSR_18" timeliness 90))
CLIPS>
(assert
   ("TSRdd_18" UNT_priority 2)
```

```
   ("TSRdd_18" pref_class_1 UHF_LOS)
   ("TSRdd_18" pref_class_2 HF_ITF HF_ABC)
   ("TSRdd_18" prob_deliv UHF_LOS 0.7)
   ("TSRdd_18" prob_deliv HF_ITF 0.6)
   ("TSRdd_18" prob_deliv HF_ABC 0.4)
   ("TSRdd_18" message_delay UHF_LOS 70)
   ("TSRdd_18" message_delay HF_ITF 80)
   ("TSRdd_18" message_delay HF_ABC 80)
   ("TSRdd_18" congestion UHF_LOS  6)
   ("TSRdd_18" congestion HF_ITF 5)
   ("TSRdd_18" congestion HF_ABC 5)
   ("TSRdd_18" max_congestion UHF_LOS 7)
   ("TSRdd_18" max_congestion HF_ITF 7)
   ("TSRdd_18" max_congestion HF_ABC 7))
CLIPS>
(run)
No candidate network is untimely or congested.

More than one candidate subnet.
Next checking their reliability.  ...

2 subnets passed the probability-of-delivery test.
The Point-to-Point Value Function will be computed for each. ...

HF_ITF:  7.18253994
UHF_LOS:  8.50793648

Maximum Value_Funtion:  8.50793648
Assign UHF_LOS to "TSR_18".

Next computing fuzzy decision for comparison....
Weighted criteria measures for HF_ITF:
       0.00604662, 0.08163266, 0.11111111, 0.33489794
Minimum is 0.00604662.
Weighted criteria measures for UHF_LOS:
       0.02824752, 0.02040816, 0.22222222, 1
Minimum is 0.02040816.
Fuzzy selection algorithm recommendation:
Assign UHF_LOS to "TSR_18".
88 rules fired
CLIPS> (run)1 rules fired
CLIPS>


(assert
   ("TSR_19" message_ID 19)
   ("TSR_19" source x)
   ("TSR_19" destination node1 node2 node3)
   ("TSR_19" trans_mode multicast)
   ("TSR_19" security GENSER/TS)
   ("TSR_19" AJ 0)
   ("TSR_19" bandwidth 0)
   ("TSR_19" length 0)
   ("TSR_19" data_type voice)
   ("TSR_19" priority 0)
   ("TSR_19" reliability 0.5)
   ("TSR_19" timeliness 90))
CLIPS>
(assert
   ("TSRdd_19" pref_class_1 UHF_LOS)
   ("TSRdd_19" pref_class_2 )
   ("TSRdd_19" prob_deliv UHF_LOS node1 0.6)
   ("TSRdd_19" prob_deliv UHF_LOS node2 0.4)
   ("TSRdd_19" prob_deliv UHF_LOS node3 0.8))
CLIPS> (run)Use of UHF_LOS approved for "TSR_19".
```

```
39 rules fired
CLIPS> (run)1 rules fired
CLIPS>


(assert
   ("TSR_20" message_ID 20)
   ("TSR_20" source x)
   ("TSR_20" destination node1 node2 node3)
   ("TSR_20" trans_mode multicast)
   ("TSR_20" security GENSER/TS)
   ("TSR_20" AJ 0)
   ("TSR_20" bandwidth 0)
   ("TSR_20" length 0)
   ("TSR_20" data_type voice)
   ("TSR_20" priority 0)
   ("TSR_20" reliability 0.5)
   ("TSR_20" timeliness 90))
CLIPS>
(assert
   ("TSRdd_20" pref_class_1 UHF_LOS)
   ("TSRdd_20" pref_class_2 )
   ("TSRdd_20" prob_deliv UHF_LOS node1 0.6)
   ("TSRdd_20" prob_deliv UHF_LOS node2 0.4)
   ("TSRdd_20" prob_deliv UHF_LOS node3 0.4))
CLIPS> (run)Sevice refused for "TSR_20".
Too few destinations can be reached on UHF_LOS.

38 rules fired
CLIPS> (run)1 rules fired
CLIPS>

(assert
   ("TSR_21" message_ID 21)
   ("TSR_21" source x)
   ("TSR_21" destination node1 node2 node3)
   ("TSR_21" trans_mode multicast)
   ("TSR_21" security GENSER/TS)
   ("TSR_21" AJ 0)
   ("TSR_21" bandwidth 0)
   ("TSR_21" length 100)
   ("TSR_21" data_type NTDS)
   ("TSR_21" priority 0)
   ("TSR_21" reliability 0.5)
   ("TSR_21" timeliness 90))
CLIPS>
(assert
   ("TSRdd_21" pref_class_1 UHF_LOS HF_ITF)
   ("TSRdd_21" pref_class_2 )
   ("TSRdd_21" prob_deliv UHF_LOS node1 0.6)
   ("TSRdd_21" prob_deliv UHF_LOS node2 0.4)
   ("TSRdd_21" prob_deliv UHF_LOS node3 0.6)
   ("TSRdd_21" prob_deliv HF_ITF node1 0.4)
   ("TSRdd_21" prob_deliv HF_ITF node2 0.4)
   ("TSRdd_21" prob_deliv HF_ITF node3 0.4))
CLIPS> (run)
Assign UHF_LOS to "TSR_21".
Its probability of delivery (averaged over destinations)
is significantly the largest.

57 rules fired
CLIPS> (run)1 rules fired
CLIPS>


(assert
```

```
   ("TSR_22" message_ID 22)
   ("TSR_22" source x)
   ("TSR_22" destination node1 node2 node3)
   ("TSR_22" trans_mode multicast)
   ("TSR_22" security GENSER/TS)
   ("TSR_22" AJ 0)
   ("TSR_22" bandwidth 0)
   ("TSR_22" length 100)
   ("TSR_22" data_type NTDS)
   ("TSR_22" priority 0)
   ("TSR_22" reliability 0.5)
   ("TSR_22" timeliness 90))
CLIPS>
(assert
   ("TSRdd_22" pref_class_1 UHF_LOS HF_ITF)
   ("TSRdd_22" pref_class_2 )
   ("TSRdd_22" prob_deliv UHF_LOS node1 0.6)
   ("TSRdd_22" prob_deliv UHF_LOS node2 0.7)
   ("TSRdd_22" prob_deliv UHF_LOS node3 0.55)
   ("TSRdd_22" prob_deliv HF_ITF node1 0.8)
   ("TSRdd_22" prob_deliv HF_ITF node2 0.6)
   ("TSRdd_22" prob_deliv HF_ITF node3 0.45))
CLIPS> (run)
HF_ITF has the highest average probability, but the next highest
      is too close.  The subnet reaching the most destinations will be
      selected.........

Assign UHF_LOS to "TSR_22".

83 rules fired
CLIPS> (run)1 rules fired
CLIPS>


(assert
   ("TSR_23" message_ID 23)
   ("TSR_23" source x)
   ("TSR_23" destination node1 node2 node3)
   ("TSR_23" trans_mode multicast)
   ("TSR_23" security GENSER/TS)
   ("TSR_23" AJ 0)
   ("TSR_23" bandwidth 0)
   ("TSR_23" length 100)
   ("TSR_23" data_type NTDS)
   ("TSR_23" priority 0)
   ("TSR_23" reliability 0.5)
   ("TSR_23" timeliness 90))
CLIPS>
(assert
   ("TSRdd_23" pref_class_1 UHF_LOS)
   ("TSRdd_23" pref_class_2 )
   ("TSRdd_23" prob_deliv UHF_LOS node1 0.6)
   ("TSRdd_23" prob_deliv UHF_LOS node2 0.7)
   ("TSRdd_23" prob_deliv UHF_LOS node3 0.55))
CLIPS> (run)
Assign UHF_LOS to "TSR_23".
It is the only available subnet.

24 rules fired
CLIPS> (run)1 rules fired
CLIPS>


(assert
   ("TSR_24" message_ID 24)
   ("TSR_24" source x)
```

```
   ("TSR_24" destination node1 node2 node3)
   ("TSR_24" trans_mode multicast)
   ("TSR_24" security GENSER/TS)
   ("TSR_24" AJ 0)
   ("TSR_24" bandwidth 0)
   ("TSR_24" length 100)
   ("TSR_24" data_type NTDS)
   ("TSR_24" priority 0)
   ("TSR_24" reliability 0.5)
   ("TSR_24" timeliness 90))
CLIPS>
(assert
   ("TSRdd_24" pref_class_1 UHF_LOS HF_ITF)
   ("TSRdd_24" pref_class_2 )
   ("TSRdd_24" prob_deliv UHF_LOS node1 0.6)
   ("TSRdd_24" prob_deliv UHF_LOS node2 0.75)
   ("TSRdd_24" prob_deliv UHF_LOS node3 0.45)
   ("TSRdd_24" prob_deliv HF_ITF node1 0.8)
   ("TSRdd_24" prob_deliv HF_ITF node2 0.6)
   ("TSRdd_24" prob_deliv HF_ITF node3 0.45))
CLIPS> (run)
HF_ITF has the highest average probability, but the next highest
      is too close.  The subnet reaching the most destinations will be
      selected.........

UHF_LOS and HF_ITF reach equal numbers of destinations.
The average probability will be used to break the tie....

Assign UHF_LOS to "TSR_24".

83 rules fired
CLIPS> (run)1 rules fired
CLIPS>


(assert
   ("TSR_25" message_ID 25)
   ("TSR_25" source x)
   ("TSR_25" destination node1 node2 node3)
   ("TSR_25" trans_mode multicast)
   ("TSR_25" security GENSER/TS)
   ("TSR_25" AJ 0)
   ("TSR_25" bandwidth 0)
   ("TSR_25" length 100)
   ("TSR_25" data_type NTDS)
   ("TSR_25" priority 0)
   ("TSR_25" reliability 0.5)
   ("TSR_25" timeliness 90))
CLIPS>
(assert
   ("TSRdd_25" pref_class_1 UHF_LOS HF_ITF)
   ("TSRdd_25" pref_class_2 )
   ("TSRdd_25" prob_deliv UHF_LOS node1 0.6)
   ("TSRdd_25" prob_deliv UHF_LOS node2 0.7)
   ("TSRdd_25" prob_deliv UHF_LOS node3 0.55)
   ("TSRdd_25" prob_deliv HF_ITF node1 0.7)
   ("TSRdd_25" prob_deliv HF_ITF node2 0.6)
   ("TSRdd_25" prob_deliv HF_ITF node3 0.55))
CLIPS> (run)
UHF_LOS has the highest average probability, but the next highest
      is too close.  The subnet reaching the most destinations will be
      selected.........

UHF_LOS and HF_ITF reach equal numbers of destinations.
The average probability will be used to break the tie....
```

```
Assign UHF_LOS or HF_ITF to "TSR_25".
They are tied in all probability-of-delivery tests.

85 rules fired
CLIPS> (run)1 rules fired
CLIPS> (assert
   ("TSR_26" message_ID 26)
   ("TSR_26" source x)
   ("TSR_26" destination node1 node2 node3)
   ("TSR_26" trans_mode multicast)
   ("TSR_26" security GENSER/TS)
   ("TSR_26" AJ 0)
   ("TSR_26" bandwidth 0)
   ("TSR_26" length 10)
   ("TSR_26" data_type datagram)
   ("TSR_26" priority 2)
   ("TSR_26" reliability 0.5)
   ("TSR_26" timeliness 90))
CLIPS>
(assert
   ("TSRdd_26" UNT_priority 4)
   ("TSRdd_26" pref_class_1 UHF_LOS)
   ("TSRdd_26" pref_class_2 HF_ITF)
   ("TSRdd_26" prob_deliv UHF_LOS node1 0.6)
   ("TSRdd_26" prob_deliv UHF_LOS node2 0.3)
   ("TSRdd_26" prob_deliv UHF_LOS node3 0.85)
   ("TSRdd_26" prob_deliv HF_ITF node1 0.6)
   ("TSRdd_26" prob_deliv HF_ITF node2 0.4)
   ("TSRdd_26" prob_deliv HF_ITF node3 0.8)
   ("TSRdd_26" message_delay UHF_LOS node1 80)
   ("TSRdd_26" message_delay UHF_LOS node2 80)
   ("TSRdd_26" message_delay UHF_LOS node3 80)
   ("TSRdd_26" message_delay HF_ITF node1 100)
   ("TSRdd_26" message_delay HF_ITF node2 100)
   ("TSRdd_26" message_delay HF_ITF node3 100)
   ("TSRdd_26" congestion UHF_LOS 8)
   ("TSRdd_26" congestion HF_ITF 5)
   ("TSRdd_26" max_congestion HF_ITF 7)
   ("TSRdd_26" max_congestion UHF_LOS 7))
CLIPS>
(run)
UHF_LOS is dropped as a candidate net because it is congested.

HF_ITF is dropped as a candidate because it is untimely.

Service is refused for "TSR_26".
No subnet passes the congestion and delay tests.

50 rules fired
CLIPS> (run)1 rules fired
CLIPS> (assert
   ("TSR_27" message_ID 27)
   ("TSR_27" source x)
   ("TSR_27" destination node1 node2 node3)
   ("TSR_27" trans_mode multicast)
   ("TSR_27" security GENSER/TS)
   ("TSR_27" AJ 0)
   ("TSR_27" bandwidth 0)
   ("TSR_27" length 10)
   ("TSR_27" data_type datagram)
   ("TSR_27" priority 2)
   ("TSR_27" reliability 0.5)
   ("TSR_27" timeliness 90))
CLIPS>
(assert
   ("TSRdd_27" UNT_priority 4)
```

```
   ("TSRdd_27" pref_class_1 UHF_LOS)
   ("TSRdd_27" pref_class_2 HF_ITF)
   ("TSRdd_27" prob_deliv UHF_LOS node1 0.6)
   ("TSRdd_27" prob_deliv UHF_LOS node2 0.3)
   ("TSRdd_27" prob_deliv UHF_LOS node3 0.85)
   ("TSRdd_27" prob_deliv HF_ITF node1 0.4)
   ("TSRdd_27" prob_deliv HF_ITF node2 0.4)
   ("TSRdd_27" prob_deliv HF_ITF node3 0.4)
   ("TSRdd_27" message_delay UHF_LOS node1 100)
   ("TSRdd_27" message_delay UHF_LOS node2 100)
   ("TSRdd_27" message_delay UHF_LOS node3 100)
   ("TSRdd_27" message_delay HF_ITF node1 70)
   ("TSRdd_27" message_delay HF_ITF node2 80)
   ("TSRdd_27" message_delay HF_ITF node3 80)
   ("TSRdd_27" congestion UHF_LOS 8)
   ("TSRdd_27" congestion HF_ITF 5)
   ("TSRdd_27" max_congestion HF_ITF 7)
   ("TSRdd_27" max_congestion UHF_LOS 7))
CLIPS>
(run)
UHF_LOS is dropped as a candidate net because it is congested and untimely.

HF_ITF is the only net to pass congestion and timeliness tests.
Next checking the percentage of destinations it reaches.

Service on "TSR_27" is refused.  No subnet passes all tests.

65 rules fired
CLIPS> (run)1 rules fired
CLIPS> (assert
   ("TSR_28" message_ID 28)
   ("TSR_28" source x)
   ("TSR_28" destination node1 node2 node3)
   ("TSR_28" trans_mode multicast)
   ("TSR_28" security GENSER/TS)
   ("TSR_28" AJ 0)
   ("TSR_28" bandwidth 0)
   ("TSR_28" length 10)
   ("TSR_28" data_type datagram)
   ("TSR_28" priority 2)
   ("TSR_28" reliability 0.5)
   ("TSR_28" timeliness 90))
CLIPS>
(assert
   ("TSRdd_28" UNT_priority 4)
   ("TSRdd_28" pref_class_1 UHF_LOS)
   ("TSRdd_28" pref_class_2 HF_ITF)
   ("TSRdd_28" prob_deliv UHF_LOS node1 0.6)
   ("TSRdd_28" prob_deliv UHF_LOS node2 0.7)
   ("TSRdd_28" prob_deliv UHF_LOS node3 0.85)
   ("TSRdd_28" prob_deliv HF_ITF node1 0.6)
   ("TSRdd_28" prob_deliv HF_ITF node2 0.4)
   ("TSRdd_28" prob_deliv HF_ITF node3 0.8)
   ("TSRdd_28" message_delay UHF_LOS node1 80)
   ("TSRdd_28" message_delay UHF_LOS node2 80)
   ("TSRdd_28" message_delay UHF_LOS node3 80)
   ("TSRdd_28" message_delay HF_ITF node1 100)
   ("TSRdd_28" message_delay HF_ITF node2 100)
   ("TSRdd_28" message_delay HF_ITF node3 100)
   ("TSRdd_28" congestion UHF_LOS 5)
   ("TSRdd_28" congestion HF_ITF 5)
   ("TSRdd_28" max_congestion HF_ITF 7)
   ("TSRdd_28" max_congestion UHF_LOS 7))
CLIPS>
(run)
HF_ITF is dropped as a candidate because it is untimely.
```

```
UHF_LOS is the only net to pass congestion and timeliness tests.
Next checking the percentage of destinations it reaches.

Assign UHF_LOS to "TSR_28".
68 rules fired
CLIPS> (run)1 rules fired
CLIPS> (assert
   ("TSR_29" message_ID 29)
   ("TSR_29" source x)
   ("TSR_29" destination node1 node2 node3)
   ("TSR_29" trans_mode multicast)
   ("TSR_29" security GENSER/TS)
   ("TSR_29" AJ 0)
   ("TSR_29" bandwidth 0)
   ("TSR_29" length 10)
   ("TSR_29" data_type datagram)
   ("TSR_29" priority 2)
   ("TSR_29" reliability 0.5)
   ("TSR_29" timeliness 90))
CLIPS>
(assert
   ("TSRdd_29" UNT_priority 4)
   ("TSRdd_29" pref_class_1 UHF_LOS)
   ("TSRdd_29" pref_class_2 HF_ITF)
   ("TSRdd_29" prob_deliv UHF_LOS node1 0.3)
   ("TSRdd_29" prob_deliv UHF_LOS node2 0.3)
   ("TSRdd_29" prob_deliv UHF_LOS node3 0.85)
   ("TSRdd_29" prob_deliv HF_ITF node1 0.6)
   ("TSRdd_29" prob_deliv HF_ITF node2 0.4)
   ("TSRdd_29" prob_deliv HF_ITF node3 0.8)
   ("TSRdd_29" message_delay UHF_LOS node1 80)
   ("TSRdd_29" message_delay UHF_LOS node2 80)
   ("TSRdd_29" message_delay UHF_LOS node3 80)
   ("TSRdd_29" message_delay HF_ITF node1 70)
   ("TSRdd_29" message_delay HF_ITF node2 80)
   ("TSRdd_29" message_delay HF_ITF node3 90)
   ("TSRdd_29" congestion UHF_LOS 5)
   ("TSRdd_29" congestion HF_ITF 5)
   ("TSRdd_29" max_congestion HF_ITF 7)
   ("TSRdd_29" max_congestion UHF_LOS 7))
CLIPS>
(run)
2 subnets pass congestion and timeliness tests.
Next checking the percentage of destinations they reach.

Assign HF_ITF to "TSR_29".
It is the only candidate to reach enough destinations.
77 rules fired
CLIPS> (run)1 rules fired
CLIPS> (assert
   ("TSR_30" message_ID 30)
   ("TSR_30" source x)
   ("TSR_30" destination node1 node2 node3)
   ("TSR_30" trans_mode multicast)
   ("TSR_30" security GENSER/TS)
   ("TSR_30" AJ 0)
   ("TSR_30" bandwidth 0)
   ("TSR_30" length 10)
   ("TSR_30" data_type datagram)
   ("TSR_30" priority 1)
   ("TSR_30" reliability 0.5)
   ("TSR_30" timeliness 90))
CLIPS>
(assert
   ("TSRdd_30" UNT_priority 2)
```

```
   ("TSRdd_30" pref_class_1 UHF_LOS)
   ("TSRdd_30" pref_class_2 HF_ITF)
   ("TSRdd_30" prob_deliv UHF_LOS node1 0.3)
   ("TSRdd_30" prob_deliv UHF_LOS node2 0.3)
   ("TSRdd_30" prob_deliv UHF_LOS node3 0.85)
   ("TSRdd_30" prob_deliv HF_ITF node1 0.4)
   ("TSRdd_30" prob_deliv HF_ITF node2 0.4)
   ("TSRdd_30" prob_deliv HF_ITF node3 0.8)
   ("TSRdd_30" message_delay UHF_LOS node1 80)
   ("TSRdd_30" message_delay UHF_LOS node2 80)
   ("TSRdd_30" message_delay UHF_LOS node3 80)
   ("TSRdd_30" message_delay HF_ITF node1 70)
   ("TSRdd_30" message_delay HF_ITF node2 80)
   ("TSRdd_30" message_delay HF_ITF node3 90)
   ("TSRdd_30" congestion UHF_LOS 5)
   ("TSRdd_30" congestion HF_ITF 5)
   ("TSRdd_30" max_congestion HF_ITF 7)
   ("TSRdd_30" max_congestion UHF_LOS 7))
CLIPS>
(run)
2 subnets pass congestion and timeliness tests.
Next checking the percentage of destinations they reach.

Service on "TSR_30" is refused.
    Neither candidate reaches enough destinations.
76 rules fired
CLIPS> (run)1 rules fired
CLIPS> (assert
   ("TSR_31" message_ID 31)
   ("TSR_31" source x)
   ("TSR_31" destination node1 node2 node3)
   ("TSR_31" trans_mode multicast)
   ("TSR_31" security GENSER/TS)
   ("TSR_31" AJ 0)
   ("TSR_31" bandwidth 0)
   ("TSR_31" length 10)
   ("TSR_31" data_type datagram)
   ("TSR_31" priority 2)
   ("TSR_31" reliability 0.5)
   ("TSR_31" timeliness 90))
CLIPS>
(assert
   ("TSRdd_31" UNT_priority 3)
   ("TSRdd_31" pref_class_1 UHF_LOS)
   ("TSRdd_31" pref_class_2 HF_ITF)
   ("TSRdd_31" prob_deliv UHF_LOS node1 0.6)
   ("TSRdd_31" prob_deliv UHF_LOS node2 0.3)
   ("TSRdd_31" prob_deliv UHF_LOS node3 0.85)
   ("TSRdd_31" prob_deliv HF_ITF node1 0.6)
   ("TSRdd_31" prob_deliv HF_ITF node2 0.4)
   ("TSRdd_31" prob_deliv HF_ITF node3 0.8)
   ("TSRdd_31" message_delay UHF_LOS node1 80)
   ("TSRdd_31" message_delay UHF_LOS node2 80)
   ("TSRdd_31" message_delay UHF_LOS node3 80)
   ("TSRdd_31" message_delay HF_ITF node1 70)
   ("TSRdd_31" message_delay HF_ITF node2 80)
   ("TSRdd_31" message_delay HF_ITF node3 90)
   ("TSRdd_31" congestion UHF_LOS 5)
   ("TSRdd_31" congestion HF_ITF 5)
   ("TSRdd_31" max_congestion HF_ITF 7)
   ("TSRdd_31" max_congestion UHF_LOS 7))
CLIPS>
(run)
2 subnets pass congestion and timeliness tests.
Next checking the percentage of destinations they reach.
```

```
Both candidates reach enough destinations.

Assign both UHF_LOS and HF_ITF to "TSR_31" since UNT priority is 3.
79 rules fired
CLIPS> (run)1 rules fired
CLIPS> (assert
   ("TSR_32" message_ID 32)
   ("TSR_32" source x)
   ("TSR_32" destination node1 node2 node3)
   ("TSR_32" trans_mode multicast)
   ("TSR_32" security GENSER/TS)
   ("TSR_32" AJ 0)
   ("TSR_32" bandwidth 0)
   ("TSR_32" length 10)
   ("TSR_32" data_type datagram)
   ("TSR_32" priority 2)
   ("TSR_32" reliability 0.5)
   ("TSR_32" timeliness 90))
CLIPS>
(assert
   ("TSRdd_32" UNT_priority 4)
   ("TSRdd_32" pref_class_1 UHF_LOS)
   ("TSRdd_32" pref_class_2 HF_ITF)
   ("TSRdd_32" prob_deliv UHF_LOS node1 0.6)
   ("TSRdd_32" prob_deliv UHF_LOS node2 0.6)
   ("TSRdd_32" prob_deliv UHF_LOS node3 0.3)
   ("TSRdd_32" prob_deliv HF_ITF node1 0.3)
   ("TSRdd_32" prob_deliv HF_ITF node2 0.6)
   ("TSRdd_32" prob_deliv HF_ITF node3 0.6)
   ("TSRdd_32" message_delay UHF_LOS node1 80)
   ("TSRdd_32" message_delay UHF_LOS node2 80)
   ("TSRdd_32" message_delay UHF_LOS node3 80)
   ("TSRdd_32" message_delay HF_ITF node1 70)
   ("TSRdd_32" message_delay HF_ITF node2 80)
   ("TSRdd_32" message_delay HF_ITF node3 90)
   ("TSRdd_32" congestion UHF_LOS 5)
   ("TSRdd_32" congestion HF_ITF 5)
   ("TSRdd_32" max_congestion HF_ITF 7)
   ("TSRdd_32" max_congestion UHF_LOS 7))
CLIPS>
(run)
2 subnets pass congestion and timeliness tests.
Next checking the percentage of destinations they reach.

Both candidates reach enough destinations.

Check for disjointness since UNT priority is 4.

Assign both UHF_LOS and HF_ITF to "TSR_32".
Each can reach at least one destination that the other cannot.
78 rules fired
CLIPS> (run)1 rules fired
CLIPS> (assert
   ("TSR_33" message_ID 33)
   ("TSR_33" source x)
   ("TSR_33" destination node1 node2 node3)
   ("TSR_33" trans_mode multicast)
   ("TSR_33" security GENSER/TS)
   ("TSR_33" AJ 0)
   ("TSR_33" bandwidth 0)
   ("TSR_33" length 10)
   ("TSR_33" data_type datagram)
   ("TSR_33" priority 2)
   ("TSR_33" reliability 0.5)
   ("TSR_33" timeliness 90))
CLIPS>
```

```
(assert
   ("TSRdd_33" UNT_priority 4)
   ("TSRdd_33" pref_class_1 UHF_LOS)
   ("TSRdd_33" pref_class_2 HF_ITF)
   ("TSRdd_33" prob_deliv_UHF_LOS node1 0.6)
   ("TSRdd_33" prob_deliv UHF_LOS node2 0.3)
   ("TSRdd_33" prob_deliv UHF_LOS node3 0.85)
   ("TSRdd_33" prob_deliv HF_ITF node1 0.6)
   ("TSRdd_33" prob_deliv HF_ITF node2 0.4)
   ("TSRdd_33" prob_deliv HF_ITF node3 0.8)
   ("TSRdd_33" message_delay_UHF_LOS node1 80)
   ("TSRdd_33" message_delay UHF_LOS node2 80)
   ("TSRdd_33" message_delay UHF_LOS node3 80)
   ("TSRdd_33" message_delay HF_ITF node1 70)
   ("TSRdd_33" message_delay HF_ITF node2 80)
   ("TSRdd_33" message_delay HF_ITF node3 90)
   ("TSRdd_33" congestion UHF_LOS 5)
   ("TSRdd_33" congestion HF_ITF 5)
   ("TSRdd_33" max_congestion HF_ITF 7)
   ("TSRdd_33" max_congestion UHF_LOS 7))
CLIPS>
(run)
2 subnets pass congestion and timeliness tests.
Next checking the percentage of destinations they reach.

Both candidates reach enough destinations.

Check for disjointness since UNT priority is 4.

UHF_LOS and HF_ITF reach the same destinations.
   The one having the greatest value function will be selected.
HF_ITF:  22.54762077
UHF_LOS:  26.54762077

Assign UHF_LOS to "TSR_33".  It has the greatest value function.
94 rules fired
CLIPS> (run)1 rules fired
CLIPS> (assert
   ("TSR_34" message_ID 34)
   ("TSR_34" source x)
   ("TSR_34" destination node1 node2 node3)
   ("TSR_34" trans_mode multicast)
   ("TSR_34" security GENSER/TS)
   ("TSR_34" AJ 0)
   ("TSR_34" bandwidth 0)
   ("TSR_34" length 10)
   ("TSR_34" data_type datagram)
   ("TSR_34" priority 2)
   ("TSR_34" reliability 0.5)
   ("TSR_34" timeliness 90))
CLIPS>
(assert
   ("TSRdd_34" UNT_priority 4)
   ("TSRdd_34" pref_class_1 UHF_LOS HF_ITF)
   ("TSRdd_34" pref_class_2)
   ("TSRdd_34" prob_deliv_UHF_LOS node1 0.6)
   ("TSRdd_34" prob_deliv UHF_LOS node2 0.3)
   ("TSRdd_34" prob_deliv UHF_LOS node3 0.85)
   ("TSRdd_34" prob_deliv HF_ITF node1 0.6)
   ("TSRdd_34" prob_deliv HF_ITF node2 0.3)
   ("TSRdd_34" prob_deliv HF_ITF node3 0.85)
   ("TSRdd_34" message_delay_UHF_LOS node1 80)
   ("TSRdd_34" message_delay UHF_LOS node2 80)
   ("TSRdd_34" message_delay UHF_LOS node3 80)
   ("TSRdd_34" message_delay HF_ITF node1 80)
   ("TSRdd_34" message_delay HF_ITF node2 80)
```

```
   ("TSRdd_34" message_delay HF_ITF node3 80)
   ("TSRdd_34" congestion UHF_LOS 5)
   ("TSRdd_34" congestion HF_ITF 5)
   ("TSRdd_34" max_congestion HF_ITF 7)
   ("TSRdd_34" max_congestion UHF_LOS 7))
CLIPS> (run)
2 subnets pass congestion and timeliness tests.
Next checking the percentage of destinations they reach.

Both candidates reach enough destinations.

Check for disjointness since UNT priority is 4.

UHF_LOS and HF_ITF reach the same destinations.
   The one having the greatest value function will be selected.
HF_ITF:  26.54762077
UHF_LOS:  26.54762077

Assign UHF_LOS or HF_ITF to "TSR_34".  They are tied.
94 rules fired
CLIPS> (run)1 rules fired
CLIPS>


(assert
   ("TSR_35" message_ID 30A5)
   ("TSR_35" source x)
   ("TSR_35" destination node1 node2 node3 node4 node5 node6 node7
 node8 node9 node10 node11 node12)
   ("TSR_35" trans_mode multicast)
   ("TSR_35" security GENSER/TS)
   ("TSR_35" AJ 0)
   ("TSR_35" bandwidth 0)
   ("TSR_35" length 100)
   ("TSR_35" data_type NTDS)
   ("TSR_35" priority 0)
   ("TSR_35" reliability 0.5)
   ("TSR_35" timeliness 90))
CLIPS>
(assert
   ("TSRdd_35" pref_class_1 UHF_LOS HF_ITF)
   ("TSRdd_35" pref_class_2 )
   ("TSRdd_35" prob_deliv UHF_LOS node1 0.6)
   ("TSRdd_35" prob_deliv UHF_LOS node2 0.75)
   ("TSRdd_35" prob_deliv UHF_LOS node3 0.45)
   ("TSRdd_35" prob_deliv UHF_LOS node4 0.6)
   ("TSRdd_35" prob_deliv UHF_LOS node5 0.75)
   ("TSRdd_35" prob_deliv UHF_LOS node6 0.45)
   ("TSRdd_35" prob_deliv UHF_LOS node7 0.6)
   ("TSRdd_35" prob_deliv UHF_LOS node8 0.75)
   ("TSRdd_35" prob_deliv UHF_LOS node9 0.45)
   ("TSRdd_35" prob_deliv UHF_LOS node10 0.6)
   ("TSRdd_35" prob_deliv UHF_LOS node11 0.75)
   ("TSRdd_35" prob_deliv UHF_LOS node12 0.45)
   ("TSRdd_35" prob_deliv HF_ITF node1 0.8)
   ("TSRdd_35" prob_deliv HF_ITF node2 0.6)
   ("TSRdd_35" prob_deliv HF_ITF node3 0.45)
   ("TSRdd_35" prob_deliv HF_ITF node4 0.8)
   ("TSRdd_35" prob_deliv HF_ITF node5 0.6)
   ("TSRdd_35" prob_deliv HF_ITF node6 0.45)
   ("TSRdd_35" prob_deliv HF_ITF node7 0.8)
   ("TSRdd_35" prob_deliv HF_ITF node8 0.6)
   ("TSRdd_35" prob_deliv HF_ITF node9 0.45)
   ("TSRdd_35" prob_deliv HF_ITF node10 0.8)
   ("TSRdd_35" prob_deliv HF_ITF node11 0.6)
   ("TSRdd_35" prob_deliv HF_ITF node12 0.45))
```

```
CLIPS> (run)
HF_ITF has the highest average probability, but the next highest
     is too close.  The subnet reaching the most destinations will be
     selected.........

UHF_LOS and HF_ITF reach equal numbers of destinations.
The average probability will be used to break the tie....

Assign UHF_LOS to "TSR_35".

That was the last message.
173 rules fired
CLIPS> (facts)
f-2      (subnet UHF_LOS)
f-3      (subnet HF_ITF)
f-4      (subnet HF_ABC)
f-5      (weights pt-pt_gram 10 2 1 6)
f-6      (weights multi_gram 10 2 1 6)
f-7      (weights pt-pt_voice 10 3 1 9)
f-11     (lastmsgnum 35)
f-3246   (currentnum 35)
f-3469   (message done)
CLIPS> (exit)
```

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Algorithms were investigated for dynamically selecting good radio frequency (RF) subnet resources to service transmission requests in a multi-internet environment. The selection algorithms were based on the communications architecture of the 1990 Unified Networking Technology (UNT) Advanced Technology Demonstration. Candidate subnet-selection algorithms were implemented in a rule-based expert system, the "C" Language Production System (CLIPS), and were tested on representative examples of transmission requests. Weighted fuzzy-logic methods were compared with a weighted-average method.

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